NEOGENE BIOSTRATIGRAPHY OF SELECTED AREAS IN THE CALIFORNIA COAST RANGES

FOR FIELD CONFERENCE ON THE MARINE NEOGENE OF CALIFORNIA
INTERNATIONAL GEOLOGICAL CORRELATION PROGRAMME (IGCP)
PROJECT 114, JUNE 21-24, 1978

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY OPEN-FILE REPORT 78-446

This report is preliminary and has not been edited
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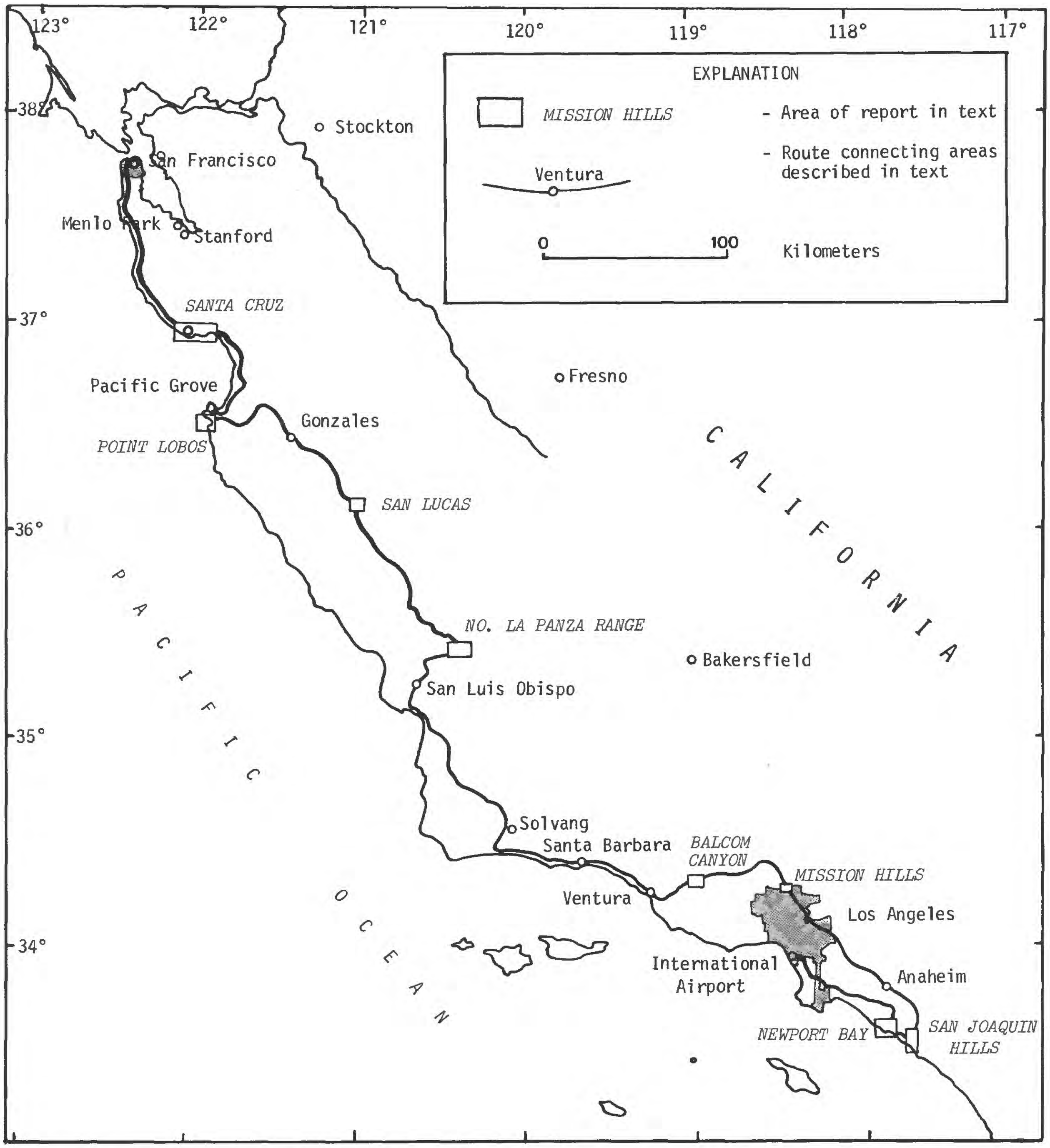
standards and nomenclature

Menlo Park, California
1978



INDEX MAP OF CALIFORNIA SHOWING AREAS DISCUSSED IN TEXT AND ROUTE CONNECTING THESE AREAS

Photographs: cover - Purisima Formation exposed in seacliffs at Santa Cruz, California; frontispiece - Astrodapsis whitneyi Remond, a late Miocene echinoid.

UNITED STATES
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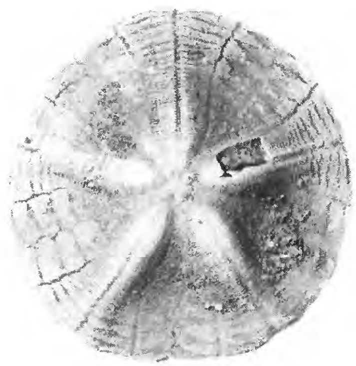
Editor

Warren O. Addicott



FIELD CONFERENCE ON MARINE NEOGENE OF CALIFORNIA

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SPONSORED BY

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U.S.G.S. OPEN-FILE REPORT 78-446 Menlo Park, California, 1978

FIELD CONFERENCE ON THE MARINE NEOGENE OF CALIFORNIA

June 21-24, 1978

Report prepared for International Geological Correlation

Programme (IGCP) Project 114, Third Working Group Meeting

in California, June 21-28, 1978

Sponsored by

The International Union of Geological Sciences

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Robert F. Meade
Richard Z. Poore

Photograph: Upper Miocene siliceous mudstone at Natural Bridges State Park, Santa Cruz, California.

CONTENTS

EDITOR'S INTRODUCTION

These papers on the marine Neogene (Miocene and Pliocene) of California are intended to provide orientation and documentation for a field conference on the Neogene biostratigraphy of the California Coast Ranges. They also constitute status reports on the age and correlation of key sections in Neogene basins of coastal California. Many new biostratigraphic data, particularly on planktic microfossils, are incorporated in these resumes.

The field conference originated from a request by leaders of Project 114 of the International Geological Correlation Programme (IGCP) - *Biostratigraphic datum-planes of the Pacific Neogene* - that the third working group meeting be convened in California. Initial meetings of this group were held in the western Pacific region - Tokyo, Japan, in 1976 and Bandung, Indonesia, in 1977. At Bandung, Professor Nobuo Ikebe, chairman of Project 114, appointed Warren O. Addicott and James C. Ingle of Stanford University to serve as co-chairmen for the meetings and a local committee was formed to set up the technical sessions and field conference. Other committee members are John A. Barron, Louie N. Marincovich, and Richard Z. Poore. The theme selected for the Project 114 meetings in California is *Correlation of tropical through high latitude marine Neogene deposits of the Pacific basin*.

The middle latitudes of southern and central California (lat 33° to 38° N.) include Neogene formations with tropical, temperate, and cool water marine faunas. This spectrum of thermal facies and the middle latitude setting of the California sections facilitate correlation between high and low latitude areas of the eastern North Pacific margin. The onshore development of marine Neogene basins is more widespread in California than in other segments of the Pacific coast of North America. As a consequence, the biostratigraphy of the California Neogene has received intensive study and is known in far greater detail than other Pacific coast areas. Thus the marine Neogene of California seems to be particularly well suited for realization of the stated objectives of these meetings.

Stratigraphic sections within the Neogene basins selected for study include fossil groups ranging from mollusks and marine vertebrates through benthic foraminifers to various planktic microfossils. Mollusks and other larger marine invertebrates were the basis of initial zonation of the Pacific coast Neogene nearly 80 years ago and continue to serve as useful biostratigraphic indices in nearshore, inner neritic facies. Benthic foraminifers have played an especially significant role in basin analysis and petroleum exploration in the California Neogene during the past 40 years. Recently, zonations based on planktic microfossils have been effectively utilized in calibrating onshore marine sections with oceanic chronologies. This development, together with recent radiometric calibration of the California Neogene, has led to fairly precise positioning of European series-epoch boundaries in the provincial sequences.

The microfossil chronologies are well-represented in the deeper water facies that characterize much of the Los Angeles and Ventura basin Neogene sequences as illustrated by the reports by Ingle and Barron on the Newport Bay, Mission Hills, and Balcom Canyon areas. Microfossils are also important in age determination and correlation of the shaly facies of the Monterey Formation that are widespread and characteristic of the Miocene of the California Coast Ranges. The interrelationship of various microfossil chronologies in the Monterey Formation of the Salinas basin is discussed by Poore, McDougall, and Barron in the report on the northern margin of the La Panza Range. Larger marine invertebrates are best developed in the relatively widespread inner neritic and littoral facies of the Salinas basin and Santa Cruz Mountains areas to be examined on this trip. They are also especially well developed in the widespread shoreline facies of the Miocene and Pliocene of the San Joaquin basin of central California.

Preparation of this report was facilitated by the helpful assistance of several people: Rose Trombley (typing and word processing), Dale Russell and Alan Murphy (drafting), Kenji Sakamoto (macrofossil photography), Robert Oscarson (scanning electron microscopy), Jack Baldauf (photographic work), and Stephany Houghton (composition). Fred Kunkel and John Newhouse were particularly helpful in readying these reports for printing. ..(W.O.A.).

NEOGENE BIOSTRATIGRAPHY AND PALEOENVIRONMENTS OF THE SAN JOAQUIN HILLS AND NEWPORT BAY AREAS, CALIFORNIA

By James C. Ingle and John A. Barron

INTRODUCTION

Over 6,200 meters of upper Oligocene through Pleistocene marine sediments are exposed in the San Joaquin Hills area of coastal southern California (figs. 1 and 2) providing an amazingly complete record of sedimentologic and paleontologic events along the southern margin of the Los Angeles Basin. Analyses of this well-known Neogene sequence in light of modern biofacies and lithofacies trends clearly illustrate that it encompasses an entire cycle of basin formation and filling beginning with subsidence in the late Oligocene, deep basin formation during the Miocene, ending with rapid turbidite sedimentation and finally neritic through littoral sedimentation in Pliocene and Pleistocene time (Natland, 1957; Ingle, 1967, 1972, in press). Although early workers recognized the importance of the San Joaquin Hills area (for example, Reed and Hollister, 1936), a detailed geologic map of the area was not published until 1957 by Vedder, Yerkes, and Schoellhamer. More recently, several field trips sponsored by the Pacific Section of the American Association of Petroleum Geologists have visited portions of this area and the resulting guidebooks (Vernon and Warren, 1970; Bergen, 1971; Fischer and Johnson, 1973) have been drawn on freely in preparing this field guide. Key paleontologic references are noted in descriptions of specific units and field trip locations.

Upper Oligocene formations of the San Joaquin Hills sequence include the nonmarine Sespe Formation and littoral sandstones of the Vaqueros Formation (fig. 2) representing evidence of the initial subsidence of this portion of the Los Angeles Basin associated with a major tectonic reorganization of the California margin induced by collision of the Farallon and North American plates (Atwater, 1970; Yeats, 1968; Snyder, Dickinson, and Silberman, 1977). Continuing subsidence is documented by more than 1,000 m of lower Miocene sands and silts of the upper Vaqueros and lower Topanga Formations representing littoral through neritic deposits (fig. 2). Middle Miocene sediments include littoral, shelf, and slope deposits of the upper Topanga Formation. This same period saw deposition of the controversial San Onofre Breccia containing distinctive clasts of glaucophane schist derived from a western basement source. Maximum subsidence and formation of a mid to lower bathyal silled basin in this area is recorded by middle and upper Miocene diatomaceous shales, diatomites, siliceous shales, and mudstones of the Monterey Shale and lower Capistrano

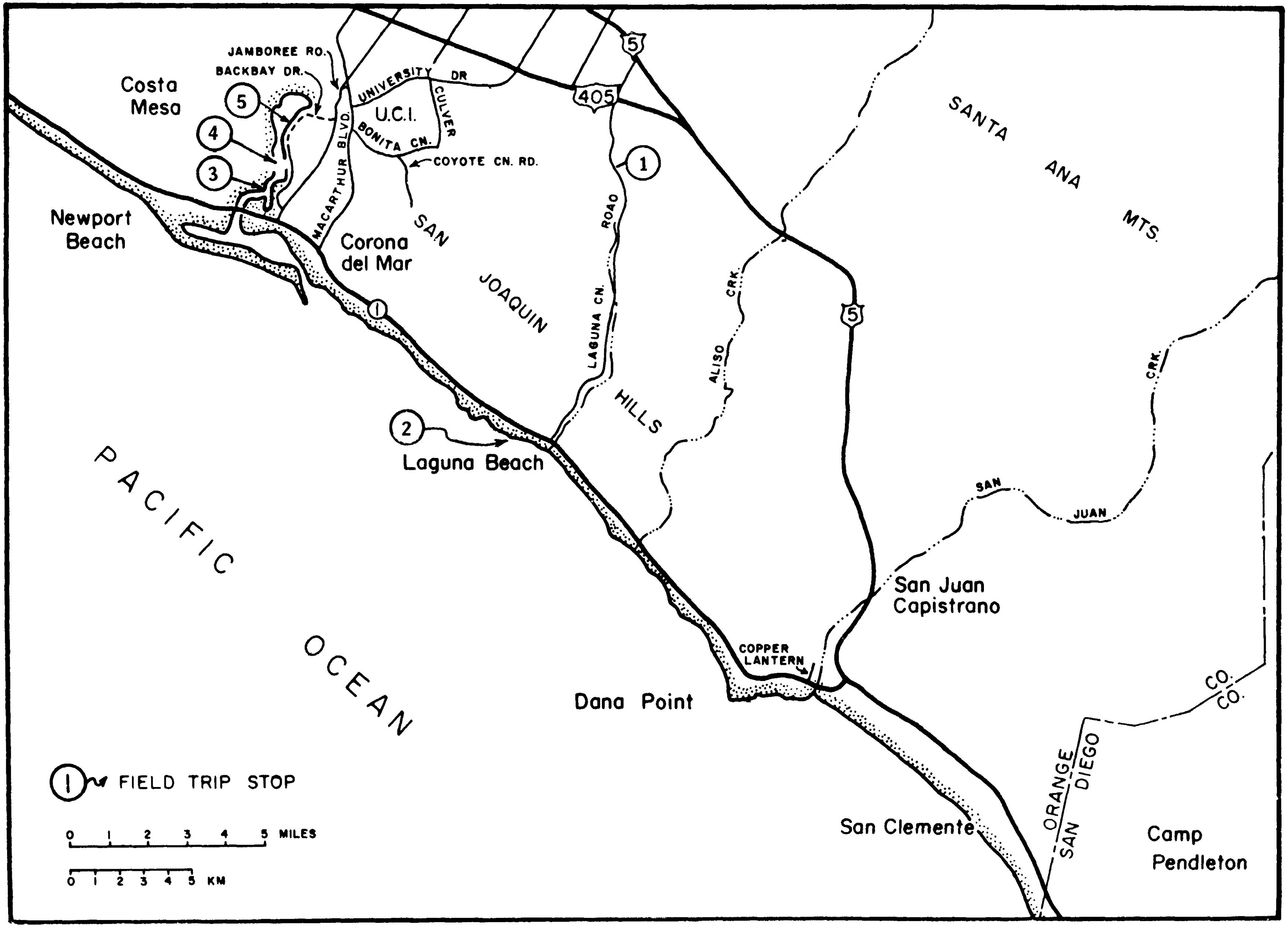


Figure 1. Location map and route of IGCP 114 field trip in the San Joaquin Hills and Newport Bay areas of southern California.

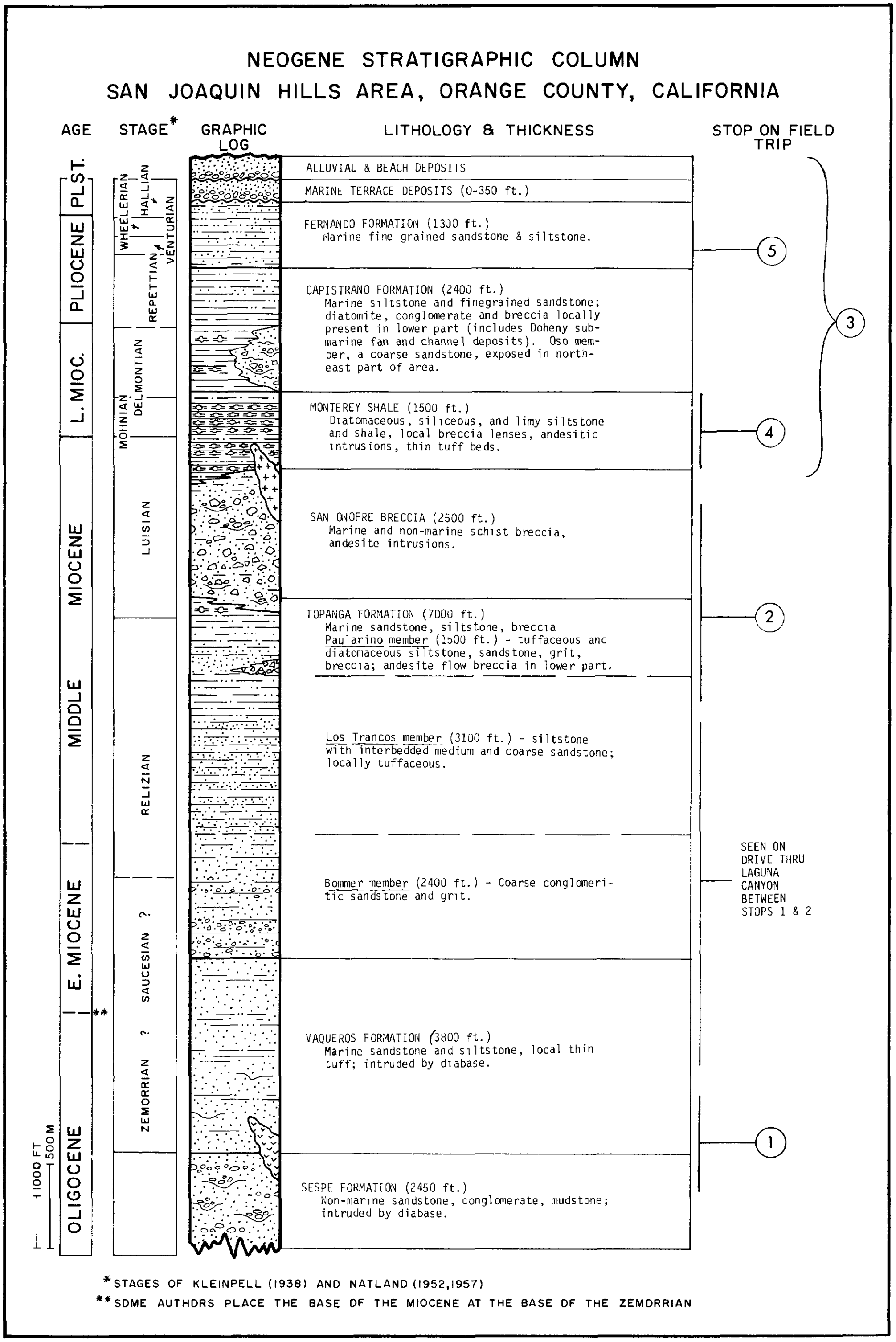


Figure 2. Composite Neogene stratigraphic column for the San Joaquin Hills area, Orange County, California (after Ingle, 1973a); IGCP 114 field trip stops marked in circles with lines covering portions of the sequence seen enroute and at stops.

Formation (fig. 2). Modern analogues of these latter deposits and microfaunas are represented by oxygen-deficient silled basins of the southern California Continental Borderland and the Gulf of California (Ingle, 1972). Increasing rates of sediment accumulation and decreasing rates of subsidence led to rapid filling of the Neogene basin during later Pliocene and Pleistocene time as evidenced by bathyal and neritic terrigenous sands and silts of the upper Capistrano and Fernando Formations (fig. 2). Pleistocene flexing of the southern California margin uplifted these deposits to their present position with repeated cutting of marine terraces along the flanks of the San Joaquin Hills during late Pleistocene time.

Many of the sedimentary units in the San Joaquin Hills sequence contain sparse to common marine megafossil and microfossil assemblages. However, the much studied middle and upper Miocene diatomaceous sediments of the Monterey Shale exposed at Newport Bay yield unusually rich and well-preserved calcareous and siliceous microfossils and comprise one of the most important Neogene reference sections along the entire Pacific coast of North America.

The route of this particular segment of the field trip begins at the intersection of the San Diego Freeway (Freeway 405) and Laguna Canyon Road (fig. 1) thence south through the lower Neogene strata of the central San Joaquin Hills to the coastal town of Laguna Beach. Miocene units will be briefly examined along the coast north of Laguna Beach with the remainder of the trip devoted to the middle Miocene through Pleistocene sequence exposed in the seacliffs surrounding Newport Bay (fig. 1).

Although this trip focuses on Neogene units it is important to note that Upper Cretaceous, Paleocene, and Eocene sediments are also exposed in the San Joaquin Hills and represent neritic deposition during an earlier cycle of marine deposition in this region. A major interval of nonmarine deposition and erosion represented by the Sespe Formation of Eocene-Oligocene age separates the late Mesozoic-Paleogene sequence from the overlying Neogene marine deposits. The field trip begins with a brief examination of interfingering nonmarine redbeds and marine sands of the Sespe and Vaqueros Formations representing the initial phases of the Neogene transgression in southern California.

FIELD TRIP ROUTE AND COMMENTS

The field trip begins at the intersection of Freeway 405 (San Diego Freeway) and Laguna Canyon Road. Upon exiting the freeway we will travel south on Laguna Canyon Road and enter the San Joaquin Hills. The initial hills flanking the highway are underlain by upper Oligocene (Zemorrian?) littoral marine sandstones assigned to the Vaqueros Formation (figs. 2 and 3). The buff and white marine sandstones of the Vaqueros Formation interfinger with underlying nonmarine redbeds of the Eocene-Oligocene Sespe Formation about 0.8 km (0.5 mile) south of the freeway exit. This gradational contact represents evidence of accelerating subsidence and initial Neogene marine transgression in this area and is typical of this event elsewhere in central and southern California.

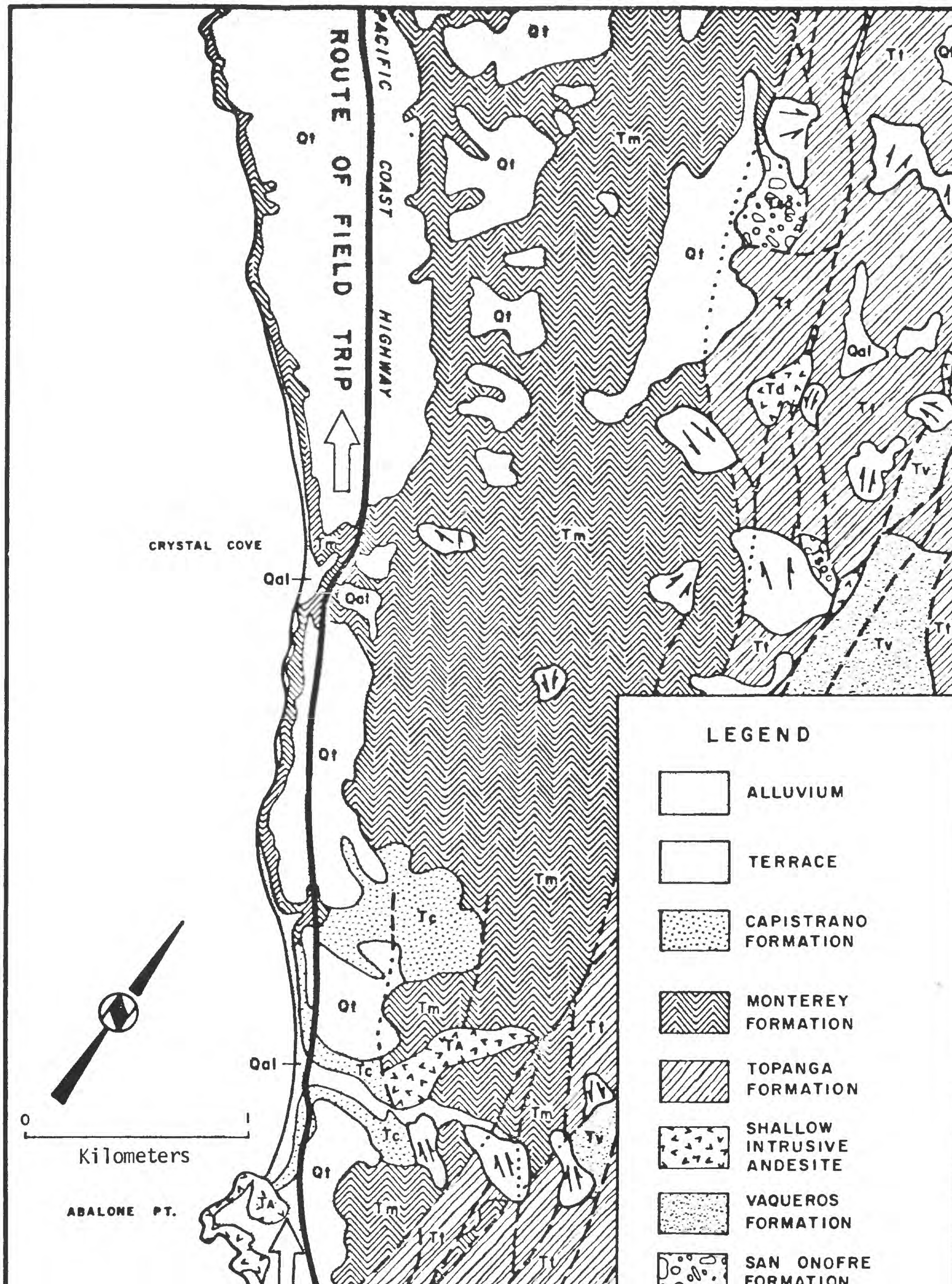


Figure 3. Geologic sketch map of Stop 1 area in Laguna Canyon; geology after Vedder, Yerkes, and Schoellhamer (1957).

STOP 1 - Prominent and well-bedded exposures of maroon silts and silty sands of the upper Sespe Formation are readily accessible in roadcuts on the east side of the highway 4.8 km (3.0 miles) south of the freeway exit. Sedimentary structures and lithology of this unit indicate it represents a portion of a major alluvial deposit cut by active streams with muddy conglomerates and pebbly mudstones likely representing debris flows (Bull, 1972).

Although the Sespe Formation has not yielded well-preserved vertebrate remains in the San Joaquin Hills correlative deposits in the type area of this unit elsewhere in southern California contain upper Eocene (Uintan) through upper Oligocene (Arikareen) faunas (Savage and Downs, 1954). More specifically, the Sespe Formation conformably overlies fossiliferous Eocene marine sands of the Santiago Formation and is conformably overlain by upper Oligocene Vaqueros beds in the San Joaquin Hills supporting a similar age range in this area.

Interestingly, the environmental significance of redbeds characterizing the Sespe Formation has been much debated with early workers assuming them to be the product of a hot and humid tropical environment. However, sedimentary features suggesting alluvial fan deposition are common in the Sespe Formation which together with its little weathered and coarse-grained character suggest deposition in a relatively dry climate with only seasonally active streams. Moreover, Walker (1967) has demonstrated that redbeds can form in arid and semiarid environments hence the current view favors a depositional setting not unlike the modern bajadas which surround the modern Gulf of California (Flemal, 1968; McCracken, 1972).

ENROUTE STOP 1 TO STOP 2 - Knobby and cavernous sandstone ridges mark exposures of the Topanga Formation in fault contact with the Sespe Formation about 1.6 km (1.0 mile) south of Stop 1 (fig. 3). Both benthic foraminifers and mollusks including locally abundant *Turritella temblorensis* and *T. ocoyana* indicate a middle Miocene age for most of the Topanga Formation (Vedder, Yerkes, and Schoellhamer, 1957; Vedder, 1970; Ingle, 1972). Some 560 m of resistant thick-bedded and cavernous sands belonging to the basal Bommer Member of the Topanga Formation (fig. 2) form prominent exposures flanking most of Laguna Canyon Road to the outskirts of the city of Laguna Beach. However, uppermost Vaqueros sandstones are present west of the highway for a distance of about 1.6 km (1.0 mile) south of the intersection of Niguel Road and Laguna Canyon Road. The contact between massive middle Miocene Topanga sandstones and underlying thin-bedded sandstones of the Vaqueros Formation is apparently conformable (Vedder, 1970). In short, the more than 3,350 m of sands and silts assigned to the Vaqueros and Topanga Formations in the San Joaquin Hills represent a transition from littoral through outer neritic deposition along a rapidly subsiding margin during late Oligocene through middle Miocene time.

STOP 2 - Traveling north 0.4 km (0.25 mile) from the intersection of Laguna Canyon Road and Pacific Coast Highway turn left on Cliff Drive and park near the lawn bowling area in Heisler Park; a paved pathway and stairs lead down to the base of the adjacent seacliffs. Stop 2 will consist of a walking traverse past seacliff exposures of lower Topanga sandstones from Recreation Point north to a prominent Miocene intrusive at Diver's Cove thence north to an exposure of San Onofre Breccia in Fisherman's Cove.

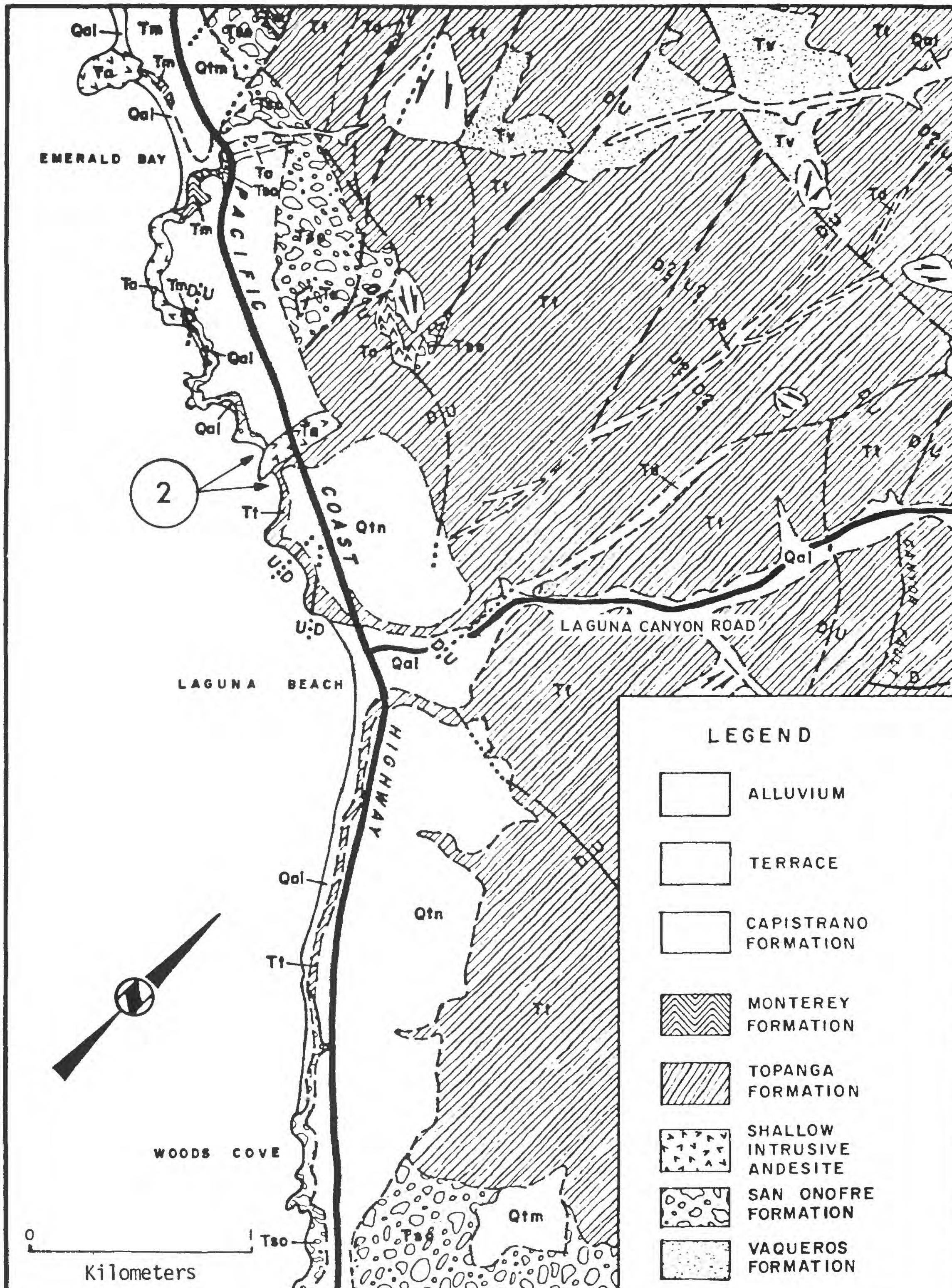


Figure 4. Geologic sketch map of Stop 2 at Heisler Park and Diver's Cove, north Laguna Beach; geology after Vedder, Yerkes, and Schoellhamer (1957).

The middle Miocene Topanga Formation at Heisler Park consists of buff well-bedded silty sands and sandy siltstones with traction structures and trace fossils indicative of littoral and inner neritic deposition.

Walking north along the base of the seacliffs a prominent coastal point composed of dark-gray intrusive andesite forms the north wall of Diver's Cove. The andesite intrusives cut the middle Miocene Topanga Formation here and elsewhere in the San Joaquin Hills indicating late Miocene emplacement. Both the Miocene shallow andesite intrusives as well as diabase dikes and sills are common in this area. The diabase dikes form a radiating pattern north and northwest from Laguna Beach intruding Paleocene through middle Miocene sedimentary rocks. Andesitic flows and breccias occur within upper Topanga sediments near Bonita Reservoir east of Newport Bay suggesting a center of later Miocene volcanic activity may have been centered in this area (Vedder, 1970).

After walking up the stairway at Diver's Cove to Cliff Drive keep left for about 15 m (25 feet) and walk downstairs along the unmarked paved pathway between seacliff apartments to Fisherman's Cove and Boat Canyon; continue past the andesite intrusive, across the beach, to the coastal point and terrace forming the north end of the cove. This latter point represents an excellent exposure of middle Miocene San Onofre Breccia.

As discussed by Stuart (1973), the San Onofre Breccia is a mixed unit of conglomerate, sandstone, mudstone, and breccia. However, the most characteristic and remarkable features of the formation are breccias with angular clasts ranging from centimeters to 3.7 m (inches to 12 feet) in diameter, poor sorting, and an abundance of glaucophane schist and other rocks from a metamorphic basement complex related to rocks composing Catalina Island off the present coast. Woodford (1925) originally studied this unit which is present over a wide area of the southern California borderland and emphasized its derivation from the Catalina Schist basement which is restricted to the area west of the present Newport-Inglewood fault zone.

Significantly, the San Onofre Breccia includes channelized redbed sequences representing alluvial fan deposition along the faulted middle Miocene strandline as well as interfingering fossiliferous marine sands and breccia lenses (Vedder, 1971). Alternately, lenses of San Onofre Breccia are known to be interbedded with bathyal Monterey Shale (Woodford, Schoellhamer, Vedder, and Yerkes, 1954) demonstrating that San Onofre sediments were simultaneously deposited along the strandline as well as in adjacent deep marine basins through downslope gravity transport.

<u>ENROUTE STOP 2 TO STOP 3</u> - Two miles (3.2 km) north of Stop 2 on Pacific Coast Highway <u>Abalone Point</u> forms another coastal prominence composed of wave-resistant upper Miocene andesite intrusives--in this case a sill with well-developed columnar jointing. North of Abalone Point and Moro Canyon Pleistocene marine terraces widen where they are cut into the less resistant lithologies of the Monterey Shale and overlying Capistrano Formation (fig. 5). Approaching Corona del Mar, the number of well-preserved higher marine terrace surfaces increase along the gentle western flank of the San Joaquin Hills. Newport Bay and surrounding Pleistocene terrace surfaces extend north and west from the San Joaquin Hills and merge with the Los Angeles basin plain.

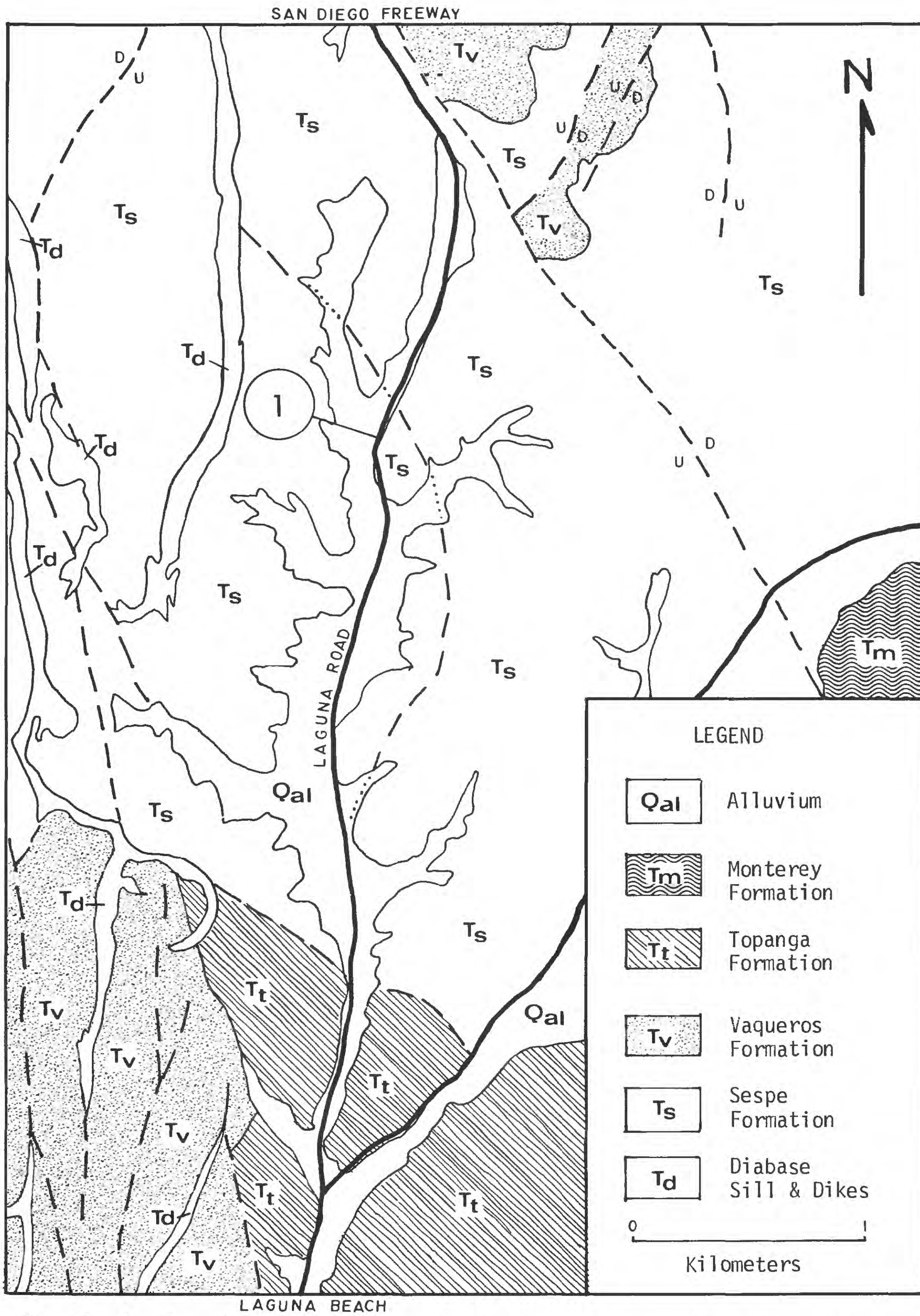


Figure 5. Geologic sketch map enroute between Laguna Beach and Newport Bay; geology after Vedder, Yerkes, and Schoellhamer (1957).

The field trip route travels north through Corona del Mar and across the bridge separating Newport Bay proper from Upper Newport Bay (fig. 6). Turn left at the intersection of Dover Drive and Pacific Coast Highway--the first intersection north of the Newport Bay bridge. Travel north on Dover Drive turning right onto Westcliff Drive passing Highland Drive and turning left onto Santiago Drive. Travel north on Santiago for 0.4 km (0.25 mile) turning right onto Marian Lane then left onto Galaxy Drive finally stopping at the prominent cliffside park (Galaxy Park) which overlooks Upper Newport Bay and represents Stop 3.

Newport Bay Section

The bluffs surrounding Upper Newport Bay contain a remarkably complete and richly fossiliferous sequence of middle Miocene through Pleistocene marine strata. These exposures are the product of late Pleistocene erosion by the ancestral Santa Ana River which cut a channel across the nose of a west-plunging anticline formed by these strata; the axis of this structure passes west directly under Galaxy Park at Stop 3 (fig. 6).

The sediments and microfossils within the Newport Bay section have been studied for well over 40 years and now constitute a major Neogene reference section for the Pacific coast of North America. Sedimentary units are best exposed along the north flank of the anticline within the eastern and western bluffs of the bay and include the middle through upper Miocene Monterey Shale, the upper Miocene through Pliocene Capistrano Formation, and the Pliocene through Pleistocene Fernando Formation (Repetto and Pico Formations of some authors); the total stratigraphic thickness of this sequence exceeds 900 meters (figs. 2, 6, and 7). Dips within the section range from 50° N. and S. near the axis of the anticline to 10° N. within Pliocene-Pleistocene sediments exposed at the extreme north end of the bay.

Abundant and well-preserved foraminiferal assemblages representative of Kleinpell's (1938) Luisian and Mohnian Stages and Natland's (1952, 1957) Repettian, Venturian, Wheelerian, and Hallian Stages can be collected from various horizons in the Newport Bay section (Natland and Rothwell, 1954) although recent construction has resulted in destruction of some well-known sample locations. Significantly, the middle and upper Miocene diatomaceous sediments of the Monterey Shale have received the most attention from biostratigraphers and continue to present an easily collected reference sequence.

Benthonic Foraminifera from the Newport Bay section and equivalent units exposed in the adjacent San Joaquin Hills have been reported on by Kleinpell (1938), Natland and Rothwell (1954), Crouch (1951), White (1956), Smith (1960), Ingle (1962, 1971, 1972), Warren (1970, 1972), and Kern and Wicander (1974). Planktonic Foraminifera from Miocene portions of the section are detailed by Lipps (1964) and both Miocene and Pliocene-Pleistocene species studied by Ingle (1972) and Asano, Ingle, and Takayanagi (1968).

Radiolaria from the Newport Bay section were originally described in a now classic monograph by Campbell and Clark (1944). More recent studies of lower Pliocene and Miocene radiolarian biostratigraphy in this sequence are presented

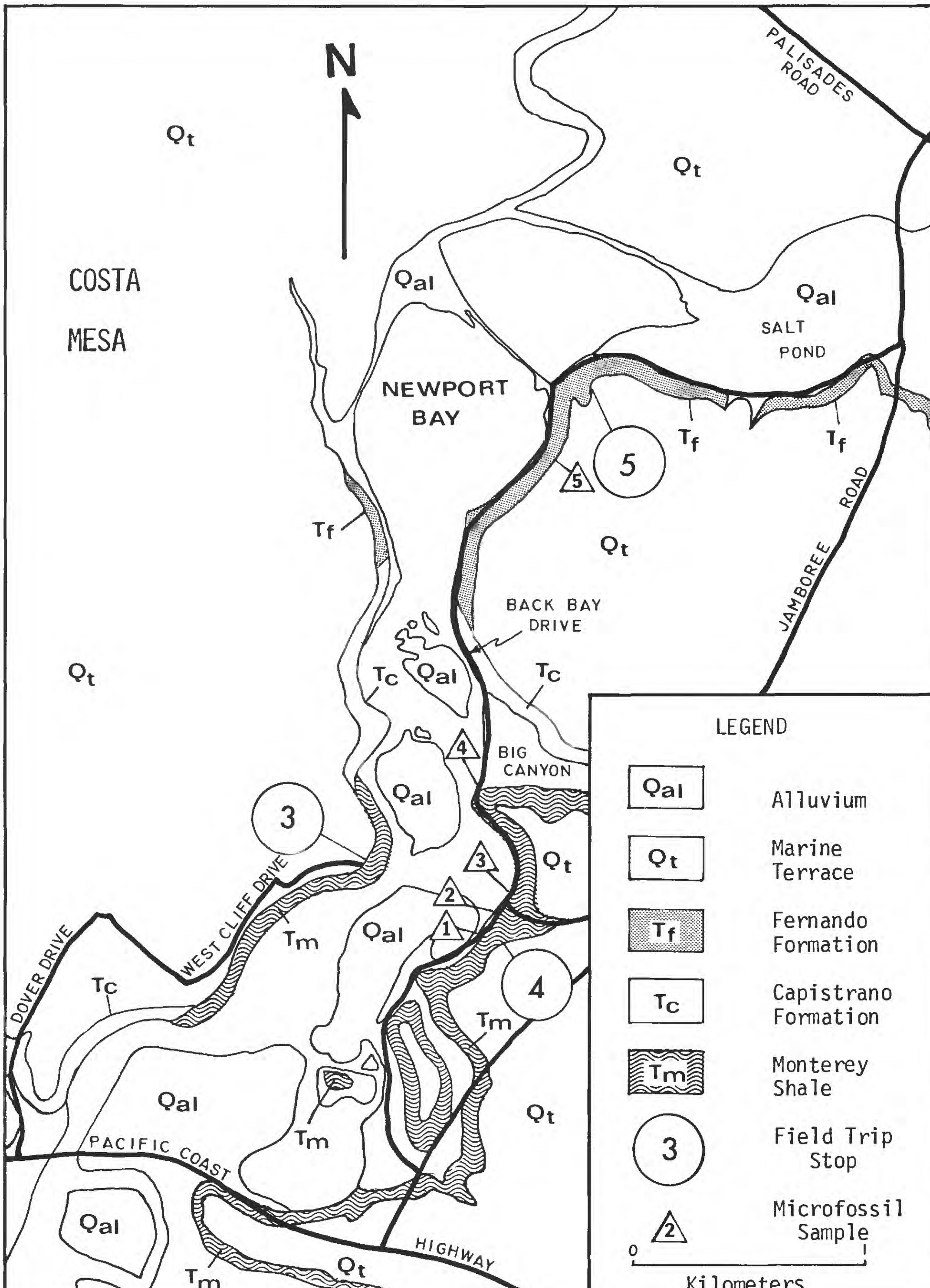


Figure 6. Geologic sketch map of the Newport Bay area and Stops 3 through 5; geology after Vedder, Yerkes, and Schoellhamer (1957). Stop 3 is an overview of the Miocene strata exposed in the east bluffs of upper Newport Bay as seen in figure 7.

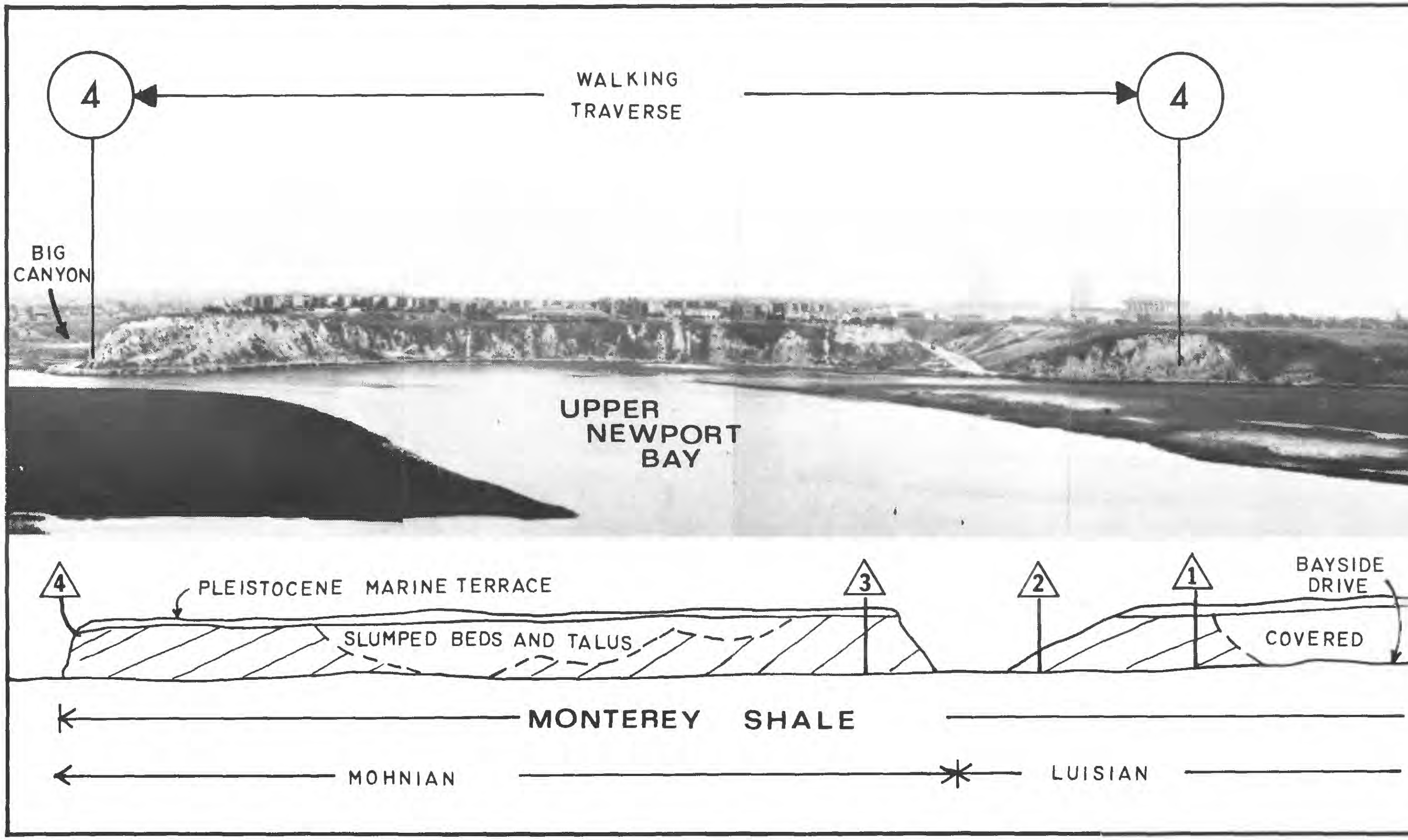


Figure 7. Looking east toward bluffs and Pleistocene terrace along east side of upper Newport Bay from Stop 3 at Galaxie View Park. This overview encompasses the entire middle and upper Miocene (middle Luisian through upper Mohnian Stages) sequence of north-dipping diatomaceous shales of the Monterey Shale. Stop 4 on the field trip involves a walking traverse along Bayside Drive through this well-known Miocene reference section. The upper Miocene and Pliocene Capistrano Formation and the overlying Pliocene and Pleistocene Fernando Formation are exposed north of Big Canyon and out of view to the left of this photograph. Numbers in triangles represent pre-collected microfossil samples provided field trip participants and noted on figure 8.

by Casey (1972), Casey, Price, and Swift (1972), and Casey and Price (1973). Ingle (1962, 1972) also includes quantitative analyses of radiolarian abundance through the entire Newport Bay section and notes the range of Prunopyle titan.

Well-preserved middle Miocene through lower Pliocene diatom floras and silicoflagellates from Newport Bay are discussed by Wornardt (1970, 1971, 1973), Cornell (1975), and Barron (1975a, b, 1976a, b).

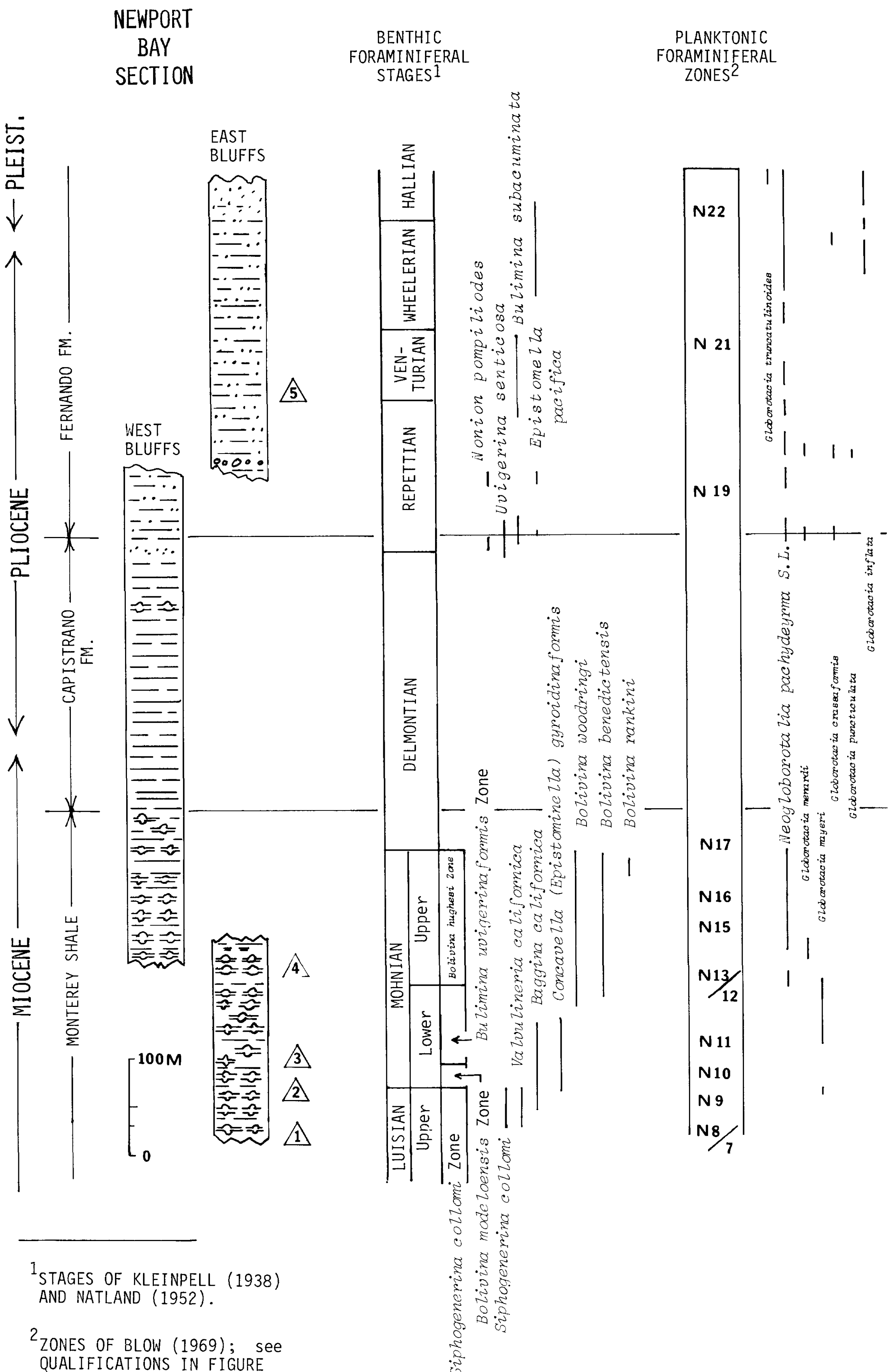
Calcareous nannoplankton from the Miocene Monterey Formation at Newport Bay have been analyzed by Martini and Bramlette (1963), Lipps (1968), Wilcoxon (1969), and Lipps and Kalisky (1972).

Finally, Vedder (1972) has summarized Pliocene molluscan assemblages from the Fernando Formation at Newport Bay with additional details of these assemblages given by Mount (1970) and Zinsmeister (1970). The very rich upper Pleistocene molluscan assemblages from Pleistocene terrace deposits unconformably overlying the Newport Bay section have been analyzed by Kanakoff and Emerson (1954).

General Stratigraphy and Paleoenvironments

The middle to upper Miocene Monterey Shale in the Newport Bay section consists of a few meters of contorted hard siliceous shales at its base grading upward into more than 300 meters of soft punky diatomaceous silts, laminated diatomites, and scattered interbeds of grey mudstone (Ingle, 1972). Prolific numbers of Foraminifera indicative of Kleinpell's (1938) middle Luisian through upper Mohnian Stages occur within the diatomaceous Monterey Shale. The stratigraphically highest portion of this unit is partially exposed at the mouth of Big Canyon in the eastern bluffs of the bay (fig. 6) where it is composed of laminated diatomites containing an upper Mohnian fauna equivalent to the Valmonte Diatomite Member of the Monterey Shale as seen in the Palos Verdes Hills (Woodring, Bramlette, and Kew, 1946).

The laminated diatomites within the Monterey Shale are direct analogues of modern laminated diatomaceous muds forming at bathyal depths under the influence of the oxygen-minimum layer within modern silled basins off southern California and the Gulf of California (Calvert, 1964; Ingle, 1972, 1973b, in press; Phleger and Soutar, 1973). In addition, benthonic foraminiferal assemblages within the Monterey Shale contain a low oxygen-restricted basin biofacies characterized by high abundances of Bolivina seminuda and related species as well as Suggrunda eckisi along with neritic and upper bathyal species displaced from the adjacent shelf and basin slope (Ingle, 1972). The presence of middle bathyal species and high radiolarian numbers within these same sediments suggests that the Neogene basin floor subsided to a depth of 1,500 meters or deeper by middle Miocene time; displaced species indicate an effective sill depth of 200-300 meters (Ingle, 1972) dictating low oxygen basin water, exclusion of a well-developed infauna, and preservation of diatomaceous lamina.



[1]STAGES OF KLEINPELL (1938) AND NATLAND (1952).

[2]ZONES OF BLOW (1969); see QUALIFICATIONS IN FIGURE CAPTION.

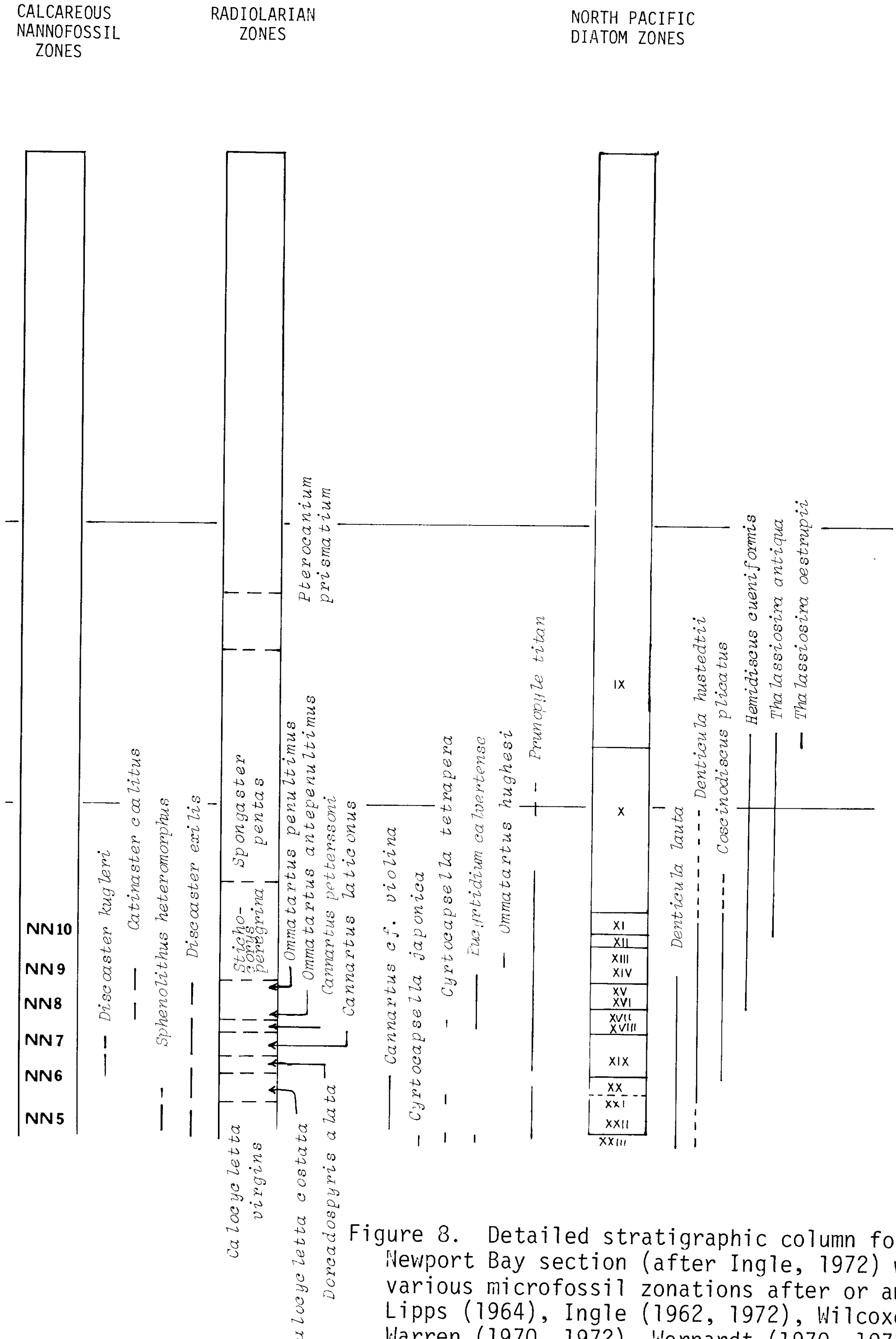


Figure 8. Detailed stratigraphic column for upper Newport Bay section (after Ingle, 1972) with various microfossil zonations after or amended from Lipps (1964), Ingle (1962, 1972), Wilcoxon (1969), Warren (1970, 1972), Wornardt (1970, 1973), Lipps and Kalisky (1972), Casey and Price (1973), and Barron (1976). Note that IGCP Project 114 microfossil sample numbers are marked in triangles.

Approximately 400 meters of massive conchoidally fracturing, red-brown mudstones and gray siltstones of the Capistrano Formation conformably overlie the Monterey Shale at Newport Bay (fig. 7). The lower mudstones of this unit are lithologically and faunally equivalent to the upper Miocene Malaga Mudstone Member of the Monterey Shale as developed in the Palos Verdes Hills to the north whereas the Pliocene sandy siltstones of the upper Capistrano are equivalent to sediments formerly referred to the Repetto Formation in the Palos Verdes Hills and central Los Angeles basin (Ingle, 1972). Radiolarian tests are abundant to common throughout the lower mudstones of the formation whereas calcareous Foraminifera are absent except for faunas within diatomites at the boundary between the Monterey Shale and Capistrano Formation (figs. 6 and 7). In fact, radiolarian numbers exceed 10,000/gm within portions of the Capistrano mudstones which together with the absence of calcareous microfossils suggests deposition of this unit took place below the local calcium carbonate compensation depth (CCD) and maximum basin subsidence to a depth approaching 2,000 meters.

A transition from the lower bathyal massive mudstones of the Capistrano Formation to siltstones and sandy silts of the upper portion of this unit (fig. 7) marks the initial appearance of a prograding wedge of coarse terrigenous base-of-slope and slope deposits onto the basin floor during early Pliocene time (Ingle, 1972). Lower bathyal foraminiferal faunas are present in both the upper Capistrano and lower Fernando Formations at Newport Bay and include Uvigerina senticosa and Melonis pompilioides.

The boundary between the Capistrano Formation and overlying 300 meters of sandy silts, siltstones, and fine sands included in the Pliocene and Pleistocene Fernando Formation is placed at a prominent conglomerate bed exposed north of Big Canyon in the east bluffs of Upper Newport Bay (figs. 6 and 7). This conglomerate as well as other coarse debris in the Fernando Formation represent evidence of turbidite deposition with the entire suite of lithologies displayed directly analogous to modern basin-fill described by Gorsline and Emery (1959) from modern nearshore basins. Moreover, the progressive appearance of lower bathyal, middle bathyal, upper bathyal, and neritic foraminiferal biofacies in the Fernando Formation records rapidly increasing rates of sediment accumulation and decreasing subsidence along the margin of the Los Angeles basin during Pliocene-Pleistocene time (Ingle, in press). The Pliocene-Pleistocene boundary as defined in terms of the initial appearance of the planktonic foraminifer Globorotalia truncatulinoides occurs in the upper Fernando Formation in sediments containing a Wheelerian Stage benthonic foraminiferal assemblage. In fact, foraminiferal faunas indicative of Natland's (1952) Pliocene Repettian, Venturian, Wheelerian, and Pleistocene Hallian Stages are present in the Fernando Formation (fig. 7), however, these assemblages are in fact facies faunas not unique to Pliocene or Pleistocene strata but instead range throughout the Pliocene to Recent with their appearance in time and space governed by basin evolution and bottom water dynamics (Natland, 1957; Ingle, 1972, 1976).

The stratigraphically highest portion of the Fernando Formation in Upper Newport Bay was destroyed during recent construction but is known to have graded from sandy siltstone to silty sand containing molluscan shells and neritic benthonic Foraminifera. An angular unconformity between these lower

Pleistocene strata and the overlying flat-lying upper Pleistocene terrace deposits dramatically demonstrates the fact that major flexing of this area occurred in middle Pleistocene time.

Age and Biostratigraphy

A summary of calcareous and siliceous microfossil zonations currently recognized in the Newport Bay section is presented on figure 8. It should be noted that the general subarctic-to-temperate character of late Neogene microfaunal and floral assemblages in this sequence has, until recently, hindered recognition of the more widely applied standard zonations developed primarily in tropical latitudes (for example, Blow, 1969. However, recent analyses of higher latitude Neogene sequences at Deep Sea Drilling Project sites in both the North and South Pacific together with recognition of major widely sensed Neogene paleoceanographic-paleoclimatic events (for example, Ingle, 1973b; Bukry, 1975; Kennett and Vella, 1975; Shackleton and Kennett, 1975; and others) have assisted in correlating the Newport Bay assemblages with standard zonal schemes as well as recognition of selected zones within the section. The dynamic Neogene history of the California current system, characterized by alternating northward and southward excursions of critical isotherms and temperature sensitive planktonic biofacies, has excluded many key tropical taxa from the Newport Bay section and allowed only brief appearances of others (Ingle, 1973b, 1977) precluding precise placement of zonal boundaries (fig. 8). Exceptions to this general case occur in terms of zonations established with siliceous microfossils. Diatom zones have now been established in low and higher latitude sequences of the North Pacific (Hays, Saito, Opdyke, and Burckle, 1969; Burckle, 1972; Schrader, 1973; Koizumi, 1973; Barron, 1976a). Many of these zones can be recognized in diatomaceous Miocene and early Pliocene sediments of the Newport Bay section (fig. 8) and together with established ranges of key silicoflagellates (Cornell, 1975; Barron, 1976b) allow correlation of this sequence with both tropical and high latitude sequences outside the California Current province as well as correlation with the working paleomagnetic and radiometric time scale commonly applied to the Neogene (Berggren and Van Couvering, 1974). Ranges of key radiolarians in general support correlations and epoch boundaries established on the basis of diatoms (Casey, Price, and Swift, 1972) as do limited planktonic foraminiferal and calcareous nannofossil ranges (Lipps, 1964, 1968; Ingle, 1972; Wilcoxon, 1969). In turn, these same correlations are providing a basis for correlating well-documented provincial benthonic foraminiferal stages and zones (Kleinpell, 1938; Natland, 1952) recognized in the Newport Bay section (Ingle, 1972; Warren, 1970, 1972) with the now widely applied planktonic zonal schemes (fig. 8).

A complicating factor surrounding the Miocene-Pliocene boundary in California is the recent recognition that the type Delmontian Stage is apparently equivalent to a portion of the older Mohnian Stage and hence constitutes an invalid stage (Pierce, 1972; Barron, 1976c). One solution might be to extend the Mohnian Stage to the base of the Repettian Stage as suggested by Pierce (1972) but further documentation of this problem will be necessary before any formal adjustment of provincial stages would be widely accepted.

A Pliocene planktonic foraminiferal fauna containing _Globorotalia crassaformis_ and _G. puncticulata_ occurs together with a Repettian benthonic foraminiferal fauna in the uppermost Capistrano Formation at Newport Bay (fig. 8) and is thought to be correlative with zone N19 of tropical latitudes.

The Pliocene-Pleistocene boundary in California is commonly placed between the provincial Wheelerian and Hallian Stages of Natland (1952) but it is widely recognized that faunas indicative of these stages range from Pliocene to Recent in age with appearance of a Hallian fauna controlled by basin-shelf history rather than evolution (for example, Ingle, 1967). Hence it is not surprising to find this epoch boundary within sediments assigned a Repettian, Venturian, Wheelerian, or Hallian provincial age. Rare specimens of _Globorotalia truncatulinoides_ occur within the uppermost Fernando Formation in the Newport Bay section and indicate the Pliocene-Pleistocene boundary as defined by the first evolutionary appearance of this species is probably present within upper Wheelerian strata of this section (fig. 8) similar to its occurrence in the western Ventura Basin to the north (Bandy and Wilcoxon, 1970).

Field Trip Locations at Newport Bay

STOP 3 - The overview of Upper Newport Bay from Galaxy Park allows the middle Miocene through upper Miocene sequence of Monterey Shale exposed in the east bluffs along Bayside Drive to be viewed in its entirety (fig. 7). Note that portions of this much studied sequence at Stop 4 are slumped and require careful sampling. Uppermost Monterey Shale and lower Capistrano sediments eroded in Big Canyon (fig. 8) are present in the west bluffs of the bay immediately north of Galaxy Park (fig. 6).

To proceed to Stop 4 retrace the route to Pacific Coast Highway (figs. 1 and 6). Turn left onto Pacific Coast Highway and travel south to the intersection of Jamboree Road. Turn left (north) onto Jamboree Road and travel a quarter mile (0.4 km) to the intersection of Bayside Drive; turn left onto Bayside Drive and proceed north to the intersection of Bayside Drive and San Joaquin Road and park. Stop 4 consists of a walking traverse past the north-dipping diatomaceous sediments of the Monterey Shale exposed along Bayside Drive from just south of San Joaquin Road north to Big Canyon (figs. 6 and 8).

STOP 4 - Rich and well-preserved foraminiferal faunas characteristic of the upper Luisian Stage occur in punky laminated diatomites initially exposed in roadcuts from a point about 200 meters south of San Joaquin Drive north to the intersection of the small canyon at the intersection of San Joaquin Road and Bayside Drive (fig. 6). Samples from these beds commonly contain abundant specimens of _Valvulineria californica_, various species of _Bolivina_, along with _Siphogenerina collomi_ (fig. 8). Planktonic foraminiferal faunas from this portion of the Monterey Shale are typically rich in _Globigerina bulloides_ s.l., _G. concinna_, _G. angustiumbilicata_, and _Globorotaloides trema_ along with rare occurrences of warmer water taxa including _Globoquadrina venezuelana_ (Lipps, 1964; Ingle, 1972). These same beds encompass North Pacific Diatom Zones XXIII through XXI and the _Calocycletta virginis_ radiolarian zone (fig. 8). Large spumellarian radiolarians can be seen on bedding planes as well as larger diatom frustules. Lipps and Kalisky (1972) assign this portion of the sequence to nannofossil zone NN5 although there is controversy over the reported occurrence of Discoaster kugleri in Luisian age beds at this location (Wilcoxon, 1969).

The laminated character of bedding within the diatomaceous shales is indicative of low oxygen bottom conditions and lack of infaunal burrowing within the silled Miocene basin. These same conditions allowed preservation of fish remains including abundant scales, teeth, and bones seen on bedding planes.

Lower Mohnian benthonic Foraminifera indicative of the Bolivina modeloensis zone occur in Monterey Shale exposed on the north side of the canyon marked by San Joaquin Road (figs. 6 and 8). The Luisian-Mohnian boundary is located within this latter canyon (Warren, 1970). Typical lower Mohnian Foraminifera found in these sediments include Concavella (Epistominella) gyroidinaformis, a distinctive index species of the California Miocene. Planktonic foraminiferal faunas continue to be dominated by temperate species with Globigerina bulloides s.l. comprising well over 50 percent of most assemblages (Ingle, 1972). Discoaster kugleri is reported to make its first and last appearances in lower Mohnian beds at this locality (Lipps and Kalisky, 1972) allowing correlation of the lower Mohnian beds with nannofossil zone NN6.

Walking north along Bayside Drive past slumped portions of the Monterey Shale good exposures are again available about 230 meters north of San Joaquin Road (fig. 6). Samples from these exposures also yield lower Mohnian bathyal Foraminifera including costate species of Uvigerina. Warren (1972) notes that the last occurrences of Baggina californica, Bolivina modeloensis, and Concavella (Epistominella) gyroidinaformis occur within this interval. Lipps and Kalisky (1972) assign this portion of the Monterey Shale to nannofossil zones NN8 and NN9(?) and place them in the uppermost middle Miocene on this basis (fig. 8).

Barron (1976) places the middle Miocene-upper Miocene boundary at the base of his modified North Pacific Diatom Zone XVI (fig. 8). Burckle (in press) suggests that the boundary lies slightly higher (probably within zonal interval XV-XVI). The base of Zone XVI corresponds with the first occurrence of Hemidiscus cuneiformis (fig. 8), a datum level that Burckle (in press) correlates with the middle of Paleomagnetic Epoch 12 (uppermost middle Miocene).

Excellent exposures of the upper Monterey Shale occur at the end of the Stop 4 traverse around the point on the south side of Big Canyon (figs. 6, 7, and 8). Warren (1972) documents the occurrence of benthonic foraminifers indicative of the Bulimina uvigerinaformis zone of the lower Mohnian up to a point 11 meters stratigraphically below the youngest exposures of Monterey Shale atop Big Canyon point (figs. 6 and 8). Upper Mohnian assemblages occur in the remaining 10-11 meters of Monterey Shale exposed on this point; younger upper Mohnian faunas are present in uppermost Monterey Shale exposed on the west side of the bay opposite Big Canyon (Ingle, 1972; Warren, 1972). Planktonic foraminifers in these strata include the first occurrence of Neogloboquadrina pachyderma with sinistral coiling populations of this species signaling the onset of subarctic surface temperatures at this locality in late Miocene time. Diatom floras are indicative of North Pacific Diatom Zones XIV and XIII (fig. 8).

Strata encompassing the Miocene-Pliocene boundary are exposed in the western bluffs of Newport Bay but will not be visited during this field trip.

Both Burckle and Opdyke (1977) and Harper (1977) place the Miocene-Pliocene boundary near the contact between the Monterey Shale and the Capistrano Formation. This is based on the occurrence of the latest Miocene diatom Nitzschia miocenica in the uppermost Monterey Shale and Casey's report (in Wornardt, 1973) of the early Pliocene radiolarian Lamprocyrtis heteroporos in the lowermost Capistrano Formation. In addition, the early Pliocene diatom Thalassiosira oestripii first appears in the lower Capistrano Formation approximately 60 m above the contact with the Monterey Shale (fig. 8) based on re-examination of Barron's (1976b) samples.

Traveling north along Bayside Drive from Stop 4 resistant pink and brown mudstones of the lower Capistrano Formation can be seen in bluffs on the north side of Big Canyon. Looking west from this point the lithologic change from the resistant mudstones to overlying gray siltstones of the upper Capistrano Formation can be seen in terms of a color change by noting increased slumping in the siltstones.

STOP 5 - After passing poorly exposed uppermost Capistrano sediments resistant conglomeratic beds of the basal Fernando Formation occur about 0.5 km (0.3 mile) north of Big Canyon; continue past this point for an additional 0.8 km (0.5 mile) to Stop 5. Low bluffs and cuts at Stop 5 contain typical exposures of micaceous sandy silts of the Pliocene-Pleistocene Fernando Formation representing the final basin-filling phase of Neogene deposition along the southeastern margin of the Los Angeles Basin (Ingle, 1972, in press). Although sediments at Stop 5 contain poorly preserved foraminifers pre-collected IGCP 114 microfossil sample 5 (figs. 6 and 8) contains a representative Pliocene foraminiferal fauna. Deepest dwelling benthonic species in sample 5 represent a middle bathyal biofacies containing Bulimina subacuminata and Uvigerina hispidocostata. This latter assemblage is also indicative of the Venturian Stage of Natland (1952, 1957). In addition, high abundances of species displaced from shallower environments such as inner neritic Nonionella miocenica stella characterize Fernando assemblages and confirm the turbidite origin of most of this unit (Ingle, 1972).

Planktonic foraminfers found within the lower Fernando Formation are dominated by Neogloboquadrina dutertrei and N. humerosa and are correlated with Pliocene zones N19 and 20. Upper portions of this formation contain planktonic foraminifers dominated by Neogloboquadrina pachyderma, Globigerina bulloides, and G. umbilicata (Ingle, 1972) with alternating zones of dextral and sinistral coiling specimens of N. pachyderma reflecting major climatic events in the northeastern Pacific (Ingle, 1972, 1977). The initial appearance of Globorotalia inflata occurs in the upper Fernando Formation with the rare occurrences of Globorotalia truncatulinoides approximating the Pliocene-Pleistocene boundary (N21/N22) in uppermost upper bathyal strata of the Fernando Fermation just prior to structural flexing and uplift of this portion of the basin margin in middle Pleistocene time.

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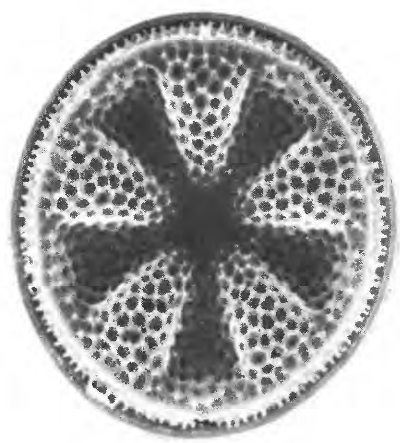

Actinoptychus vulgaris var. monicae Grunow, Upper Miocene
Montery Shale, Lompoc, Calif.

NEOGENE SECTION AT THE MISSION HILLS

by John A. Barron and James C. Ingle

The Mission Hills are located in the northeastern corner of the San Fernando Valley, California, a major east-west depression formed by Plio-Pleistocene uplift of the surrounding Santa Monica, Santa Susana, and San Gabriel Mountains. Neogene marine sediments assigned to the Modelo, Towsley (Repetto or Fernando Formations of some workers), and Pico Formations are well exposed in roadcuts which cut across the northwest strike of the Mission Hills Anticline (fig. 1). This latter structure and associated faults are also the product of Pleistocene flexing of this area with the 1971 San Fernando earthquake, attesting to continued tectonic activity. Both sediments and microfaunas indicate that the Mission Hills sequence is most closely related to the eastern Ventura Basin rather than to the Los Angeles Basin to the south. Nevertheless, complex structural relationships across the Santa Susana thrust obscure correlations with the eastern Ventura Basin sequence to the north.

STOP 1. OVERVIEW OF THE SAN FERNANDO VALLEY

The San Gabriel Mountains form the jagged ridge line to the northeast and east of the overlook. This range encompasses in excess of 1,450 square kilometers (900 square miles) of igneous and metamorphic rocks including Precambrian gneiss and amphibolite, Permian-Triassic granodiorite, and Mesozoic granitic rocks (Ehlig in Oakeshott, 1975).

Looking south, the low and relatively rounded Santa Monica Mountains mark the southern boundary of San Fernando Valley. The northern flank of this east-west range is composed primarily of north-dipping middle and upper Miocene marine sediments and volcanics of the Topanga and Modelo Formations. Smaller exposures of lower Tertiary marine and nonmarine strata, along with Mesozoic sedimentary and metasedimentary rocks, and Mesozoic granitic rocks are also present in the Santa Monica Mountains with the anticlinal core of the range formed by Jurassic Santa Monica slate.

From the west side of the parking lot the nearby Santa Susana Mountains can be seen running west along the northern edge of the San Fernando Valley, with the associated Chatsworth Hills forming a low knobby ridge at the far west end

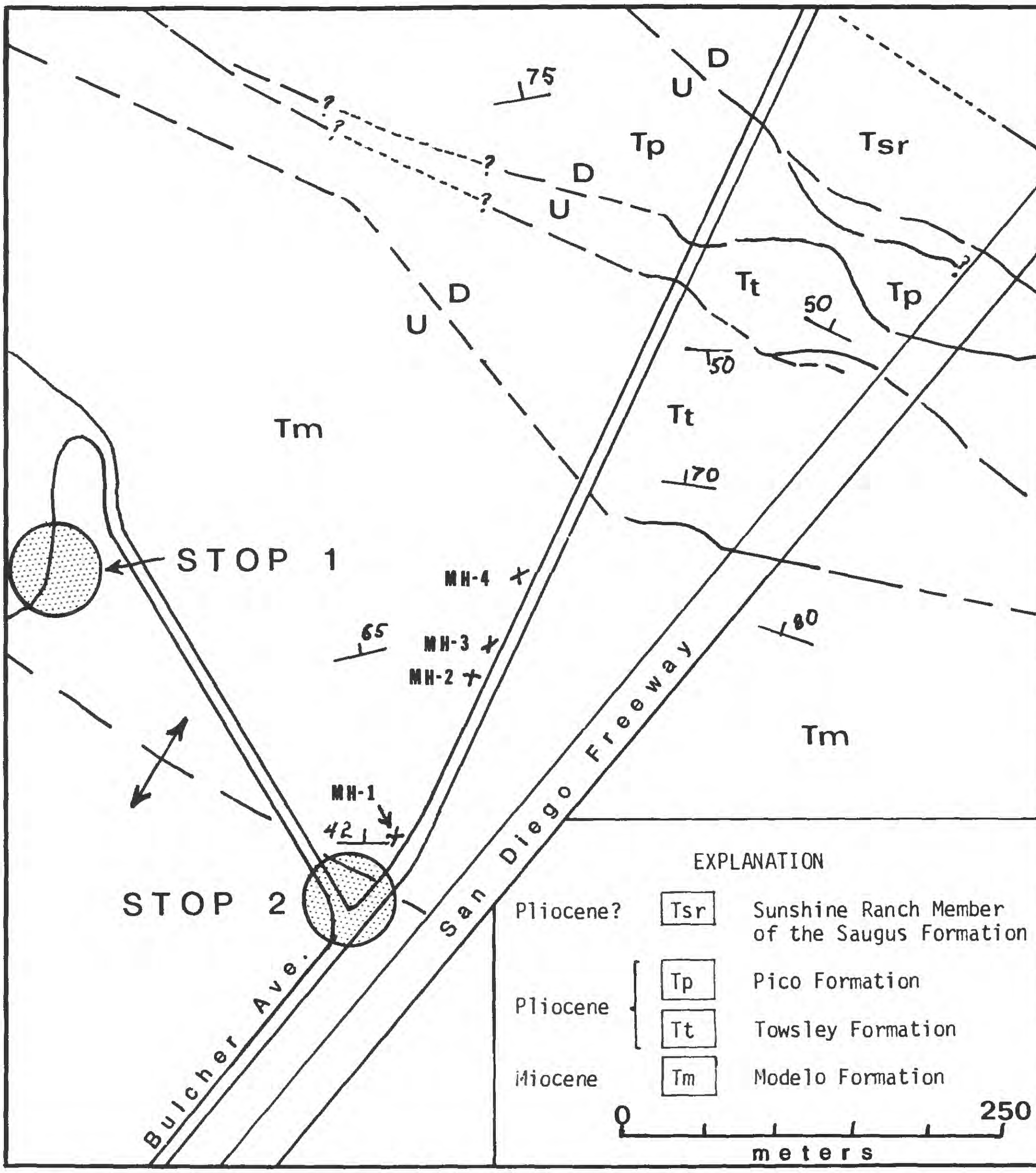

Figure 1. Mission Hills generalized geologic map. Compiled from Yerkes and others (1973) and Oakeshott (1975).

of the valley. The Santa Susana Mountains contain Upper Cretaceous marine shales and sandstones, lower Tertiary marine and nonmarine strata, as well as Miocene and Pliocene marine sediments similar to those exposed in the related Mission Hills.

It is of special interest at this stop to note that the Mission Hills area was directly involved in the devastating San Fernando Earthquake which occurred at 6 a.m. on February 9, 1971. This quake had a Richter magnitude of 6.5, and badly damaged the nearby communities of San Fernando, Saugus, and Sylmar (fig. 1) with a loss of 64 lives--total monetary loss in the greater Los Angeles area was estimated at $511 million (Oakeshott, 1975). Seismological records place the epicenter of this quake approximately 16 km (10 miles) north of the STOP 1 overlook in the western San Gabriel Mountains. Surface faulting associated with the quake occurred mainly along the trace of the San Fernando Fault (Oakeshott, 1975).

The Lower Van Norman Dam can be seen immediately west of STOP 1. At the time of the San Fernando quake, the reservoir behind the dam was approximately half filled with water. The earthquake severely damaged this hydraulic earthfill dam; according to Cortright (in Oakeshott, 1975), "the embankment including the parapet wall, the dam crest, most of the upstream slope, and a portion of the downstream slope for a length of about 1,800 feet slid into the reservoir, resulting in a loss of about 30 feet of dam height." In short, the dam was in immediate danger of failing, and thousands of residents in the area below the dam were evacuated. A major disaster was ultimately avoided by quickly turning off inflow into the lake and pumping water out of the reservoir.

STOP 2. MISSION HILLS STRATIGRAPHIC SECTION

Good exposures of faulted and north-dipping marine beds of the Modelo, Towsley, and Pico Formations and the Sunshine Ranch Member of the Saugus Formation can be examined by walking north along Bulcher Avenue from the axis of the Mission Hills anticline (fig. 1).

Modelo Formation

The upper Miocene Modelo Formation as exposed in Mission Hills is composed primarily of platy and(or) punky gray to white diatomaceous shale and minor limy concretionary layers (Saul in Oakeshott, 1975). The shales contain rare to common and poor to well-preserved diatoms, silicoflagellates, radiolarians, and foraminifers. The presence of laminated diatomites, together with a benthic foraminiferal fauna characteristic of low-oxygen conditions, suggest this unit was deposited in a silled basin containing oxygen-deficient water similar to restricted basins of modern continental borderland off southern California (Ingle, 1967). However, displaced shelf through upper bathyal species compose over 80 percent of some foraminiferal assemblages (fig. 2) and indicate downslope transport of fine-grained material was common in this portion of the basin. At the same time, massive amounts of coarse debris were invading the basin to the south in the form of the Tarzana Fan (Ingle, 1967, p. 270).

Benthic foraminifers recorded from this location (Ingle, 1967) include *Bolivina benedictensis* and *Discorbinella valmonteensis* and place this portion of Modelo Formation within the upper Mohnian Stage (upper Miocene) of Kleinpell (1938). Planktic foraminifers recorded from the Modelo shales at Mission Hills (Ingle, 1967) include *Globigerina bulloides*, *G. decoraperta*, *G. quinqueloba*, *Globigerinita glutinata*, *G. uvula*, *Globigerinoides trilobus immaturas*, *Orbulina universa*, *Neogloboquadrina acostaensis*, *N. pachyderma*, and *Sphaeroidinellopsis seminulina* (fig. 2), also indicative of an uppermost Miocene age for this unit equivalent to Neogene zone N17. The presence of

Figure 2. Benthic and planktic foraminifer trends within the Mission Hills section (from Ingle, 1967). Ingle's (1967) Repetto Formation is referred to as the Towsley Formation of Winterer and Durham (1962). Key to benthic faunal groups is as follows: (1) shelf species, (2) upper bathyal species, (3) upper middle bathyal species, (4) lower middle bathyal species, and (6) closed basin impoverished species.

Globigerinoides and Sphaeroidinellopsis within the otherwise temperate planktic fauna suggest surface water temperatures were somewhat warmer than those prevailing off southern California today.

Samples MH-1 through MH-4 of the Modelo Formation (fig. 1) were analyzed for diatoms by Barron for this report; results of these analyses can be summarized as follows:

MH-1 Moderately to poorly preserved diatom assemblage dominated by fragments of *Coscinodiscus marginatus*, *Thalassiothrix longissima*, and *Thalassionema nitzschioides*. The presence of *Denticula hustedtii*, *Actinocyclus ingens*, and *Rhizosolenia barboi*, and the absence of *Denticula lauta* and *D. dimorpha* suggest correlation with Koizumi's (1975) *Denticula hustedtii* Zone of upper Miocene age.

MH-2 Stratigraphically important diatoms in this sample include *Actinocyclus ingens*, *Actinoptychus minutus*, *Denticula hustedtii*, *Rouxia californica*, and *Thalassiosira antiqua*. The silicoflagellate *Distephanus pseudofibula* is also present. This assemblage correlates with Barron's (1976) Subzone a of upper Miocene North Pacific Diatom Zone XI and likely correlates with the upper part of Koizumi's (1975) *Denticula hustedtii* Zone.

MH-3 Contains a diatom assemblage very similar to sample MH-2 but includes *Nitzschia fossilis* and lacks *Thalassiosira antiqua*; lack of *T. antiqua* is likely due to ecological exclusion, as this sample overlies sample MH-2. This assemblage also correlates with Barron's (1976) upper Miocene Subzone a of North Pacific Diatom Zone XI and the upper part of Koizumi's (1975) *Denticula hustedtii* Zone.

MH-4 Contains a poorly preserved diatom assemblage composed predominantly of fragments of *Thalassionema nitzschioides*, *Thalassiothrix longissima*, and *Coscinodiscus* along with diatom resting spores, and benthic diatoms. Very rare specimens of *Thalassiosira antiqua* and the silicoflagellate *Distephanus speculum* var. (two elongated spines) are also present. The latter species of silicoflagellate is generally common in upper Miocene sediments of southern California.

Towsley Formation

A reverse fault separates the upper Miocene Modelo Formation from the overlying Pliocene Towsley Formation in the Mission Hills section (fig. 1). The Towsley Formation was originally described from the eastern Ventura Basin by Winterer and Durham (1962). This unit consists of dark-gray to black, brown-weathering shale in the Mission Hills (Saul *in* Oakeshott, 1975) and was previously referred to the Repetto Formation by Ingle (1967).

Pliocene middle bathyal and displaced upper bathyal benthic foraminifers have been reported from the Towsley Formation at this location (Ingle, 1967) and, together with sedimentologic evidence, suggest this unit was deposited at a depth of 1,500 m or deeper within a submarine fan complex; common species include *Bolivina acuminata*, *Cibicides fletcheri*, *Epistominella subperuviana*, *Uvigerina hispidocostata*, *U. hootsi*, and *U. peregrina*.

Winterer and Durham (1962) note that lower Pliocene megafossils are present in the Towsley Formation in the Santa Susana Mountains west of the Mission Hills, including "*Nassa*" *hamlini* and *Acila semirostrata*.

Pico Formation

A reverse fault separates the Pliocene Towsley Formation from the overlying Plio-Pleistocene Pico Formation in the Mission Hills (fig. 3). The Pico Formation at this location consists of gray fine silty sandstone and

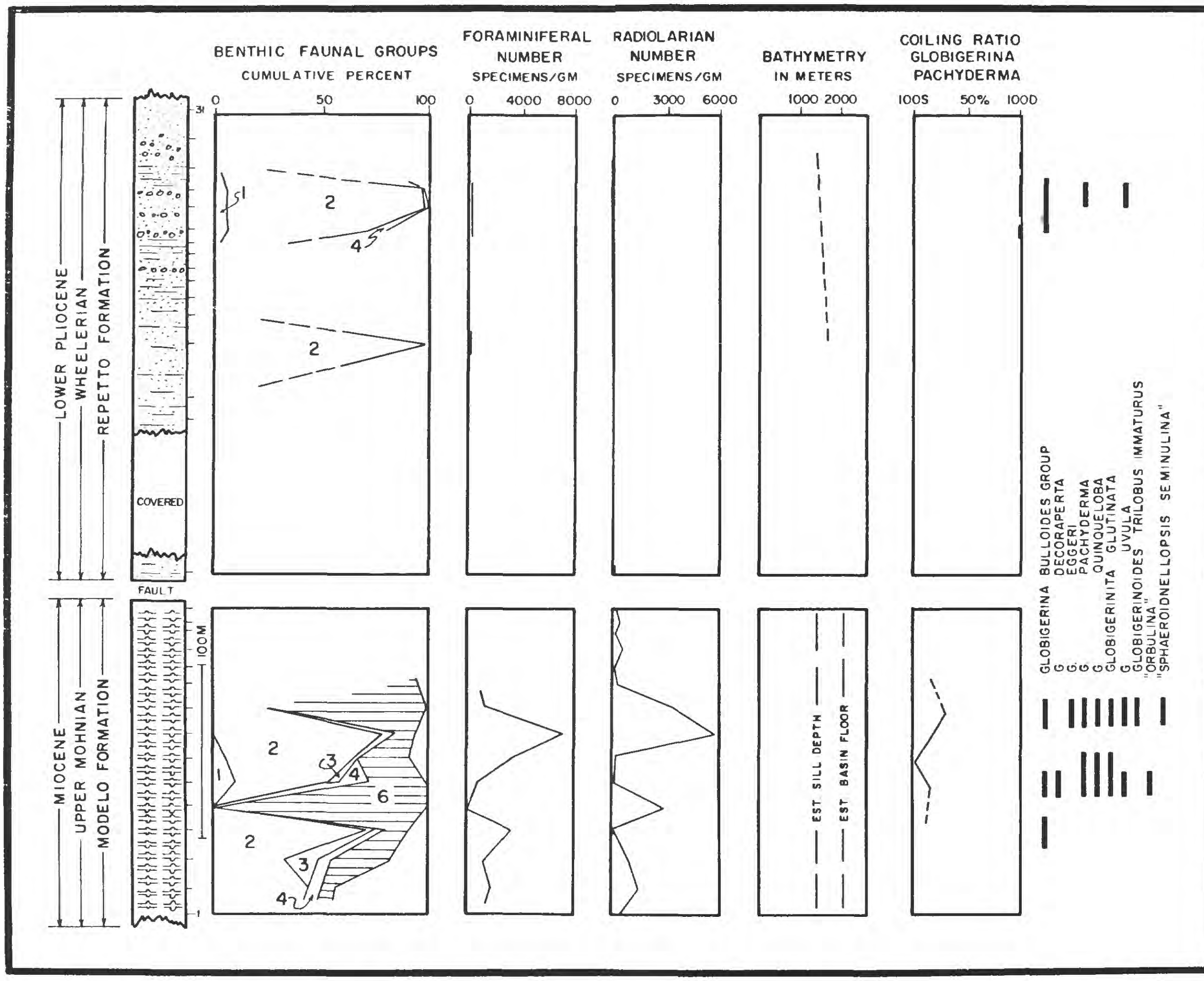

Figure 3. Faulted contact between the Pliocene Towsley Formation (left) and the Pliocene Pico Formation (right) in the Mission Hills.

conglomerate. No microfossils or megafossils have been reported from this locality, although the unit is assumed to be marine in origin. Pliocene and Pleistocene megafossils and foraminifers are common in Pico sediments of the adjacent eastern and western Ventura Basin.

Saugus Formation

The Sunshine Ranch Member of the Pliocene Saugus Formation is faulted over the Pico Formation in Mission Hills (fig. 1). This member is a nonmarine unit composed of conglomerate, sandstone, and siltstone (Saul in Oakeshott, 1975). Teeth of a late Hemphillian or early Blancan (latest Miocene-Pliocene) horse are reported from the Sunshine Ranch Member of the Saugus Formation by C. A. Repenning at a locality about 180 m below the top of the formation and approximately 1,000 m to the north of the northern edge of figure 1 (Saul in Oakeshott, 1975).

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U.S. DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY

Right-coiling form of Neogloboquadrina pachyderma (Ehrenberg)

NEOGENE BIOSTRATIGRAPHY AND PALEOENVIRONMENTS OF THE WESTERN VENTURA BASIN WITH SPECIAL REFERENCE TO THE BALCOM CANYON SECTION

by James C. Ingle

INTRODUCTION

The western portion of the Ventura Basin contains one of the thickest known Neogene marine sections in the world with a continuous sequence of Pliocene and Pleistocene marine strara near Santa Paula, California (fig. 1) exceeding 6,200 meters in thickness. When these Pliocene-Pleistocene deposits are added to the adjacent sequence of upper Cretaceous through Miocene strata exposed in the adjacent Santa Ynez Mountains (fig. 1) the total stratigraphic thickness exceeds 18,000 meters representing the combined product of major tectonic episodes of rapid subsidence and sedimentation along this portion of the California margin (fig. 2).

The Ventura Basin has undergone unusually detailed geologic scrutiny over the past half century in conjunction with intense exploration and production of petroleum. Thus, abundant subsurface as well as surface geologic and paleontologic data present an almost laboratory-like setting in which to reconstruct the history of this marginal basin. In fact, the use of fossil foraminifers for paleoenvironmental analysis was pioneered within Pliocene-Pleistocene sediments of the Ventura Basin by Natland (1933). The same area also served as a principal testing ground for early notions regarding turbidite sedimentation and associated displaced shallow-water faunas (Natland and Kuenen, 1951). Emery (1960) and others have discussed the similarity in sedimentologic patterns in the modern nearshore basins of the southern California Continental Borderland and those in the now filled Los Angeles and Ventura basins. More recent tectonic, paleobathymetric, paleomagnetic, and radiometric age analyses have demonstrated that significant portions of the Ventura Basin sequence are much younger than expected in turn demanding much higher rates of subsidence and sediment accumulation than heretofore assumed (Yeats, 1977; Ingle, in press). For example, Yeats (1977) estimates that the basin subsided at rates of up to 9.5 mm/yr until about 0.6 million years ago when subsidence ceased; since then the north margin of the basin has apparently been rising at an average rate of 10 mm/yr. Similar accelerated rates are presented by Ingle (in press) as illustrated on figure 2. In short, the Ventura Basin constitutes a premier area in which to study the character of lithofacies and biofacies changes in an ecologically, climatically, and tectonically dynamic

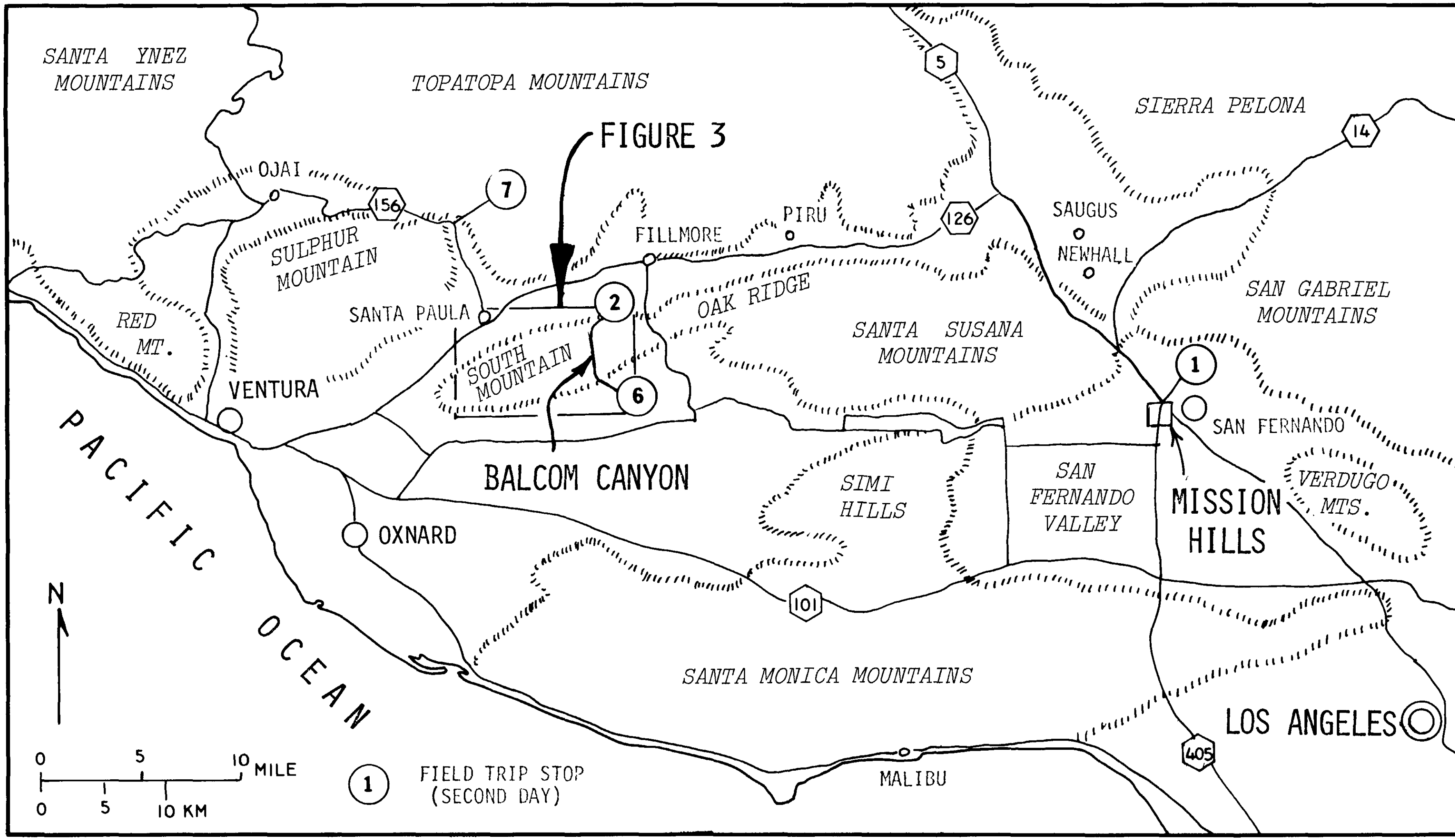


Figure 1. Location map showing Stops 1 through 7 in the Mission Hills and Ventura Basin areas of southern California and day two route of IGCP Project 114 field trip.

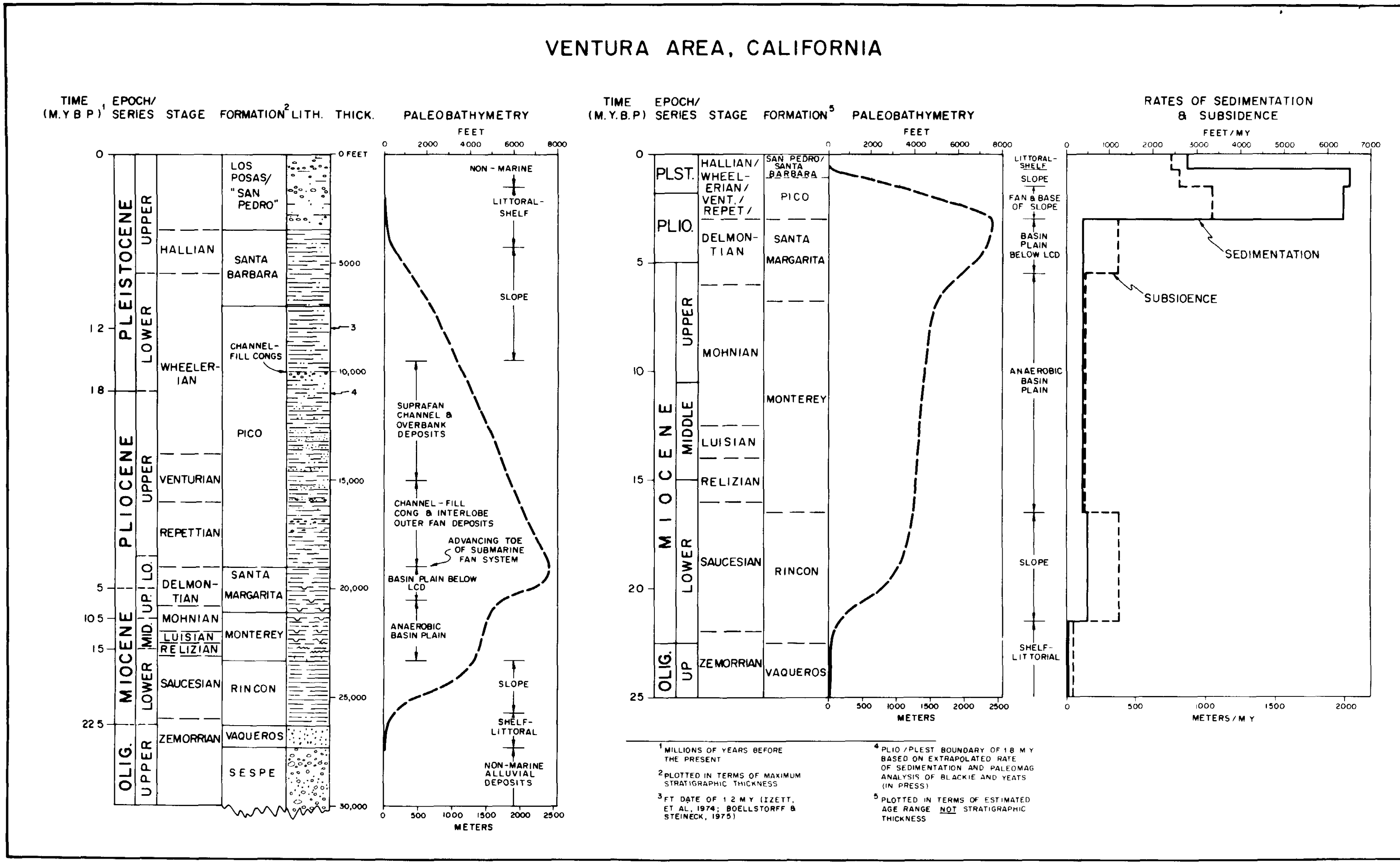


Figure 2. Paleobathymetry and marine paleoenvironments within Neogene deposits of the western Ventura Basin, California. Note that paleobathymetry is plotted in terms of maximum stratigraphic thickness of each formation and alternately in terms of estimated duration of each unit in time following the correlations presented by Ingle (in press). Chronostratigraphy incorporates fission track ages reported by Izett, Naeser, and Obradovich (1974) and Boellstorff and Steineck (1975) and the paleomagnetic data of Blackie and Yeats (1976). Estimated paleobathymetry is based on biofacies analysis of benthonic Foraminifera reported from these units by Natland (1933, 1952, 1957), Natland and Kuenen (1951), and Ingle (1967). This figure is from Ingle (in press).

area. In addition, the unusually high rates of sediment accumulation have expanded Pliocene-Pleistocene paleontologic trends in a manner that allows unusually detailed analysis where faunas are well preserved. This portion of the IGCP Project 114 field trip will focus on paleontologic and sedimentologic trends within the excellent exposures of the Pliocene-Pleistocene Pico and San Pedro formations in Balcom Canyon in the South Mountain area of the western Ventura Basin (figs. 3-6).

Neogene marine history in the Ventura Basin begins with initial subsidence and transgression in late Oligocene time coincident with initiation of marginal basin formation elsewhere along the Pacific coast of North America and the Pacific rim in general (Ingle, 1973). This major tectonic event was apparently induced by the collision and migration of ridge segments along the western edge of the North American plate, the birth of the San Andreas transform and associated translation tectonic deformation of this region (Atwater, 1970; Snyder, Dickinson, and Silberman, 1976).

Paleobathymetric analyses of the Ventura Basin sequence (Bandy, 1953; Ingle, in press) demonstrate that subsidence of the east-west basin outpaced rate of sediment accumulation during the early Miocene with accompanying formation of silled basins containing oxygen deficient water allowing formation of laminated diatomaceous silts of the Monterey (Modelo) Shale similar to somewhat later events in the adjacent Los Angeles Basin (fig. 2) as reviewed in the San Joaquin Hills-Newport Bay areas (Ingle and Barron, this volume). Maximum point of basin subsidence occurred during late Miocene deposition of radiolarian-rich muds of the Santa Margarita Formation deposited below the local lysocline and(or) calcium carbonate compensation depths (fig. 2). Major wedges

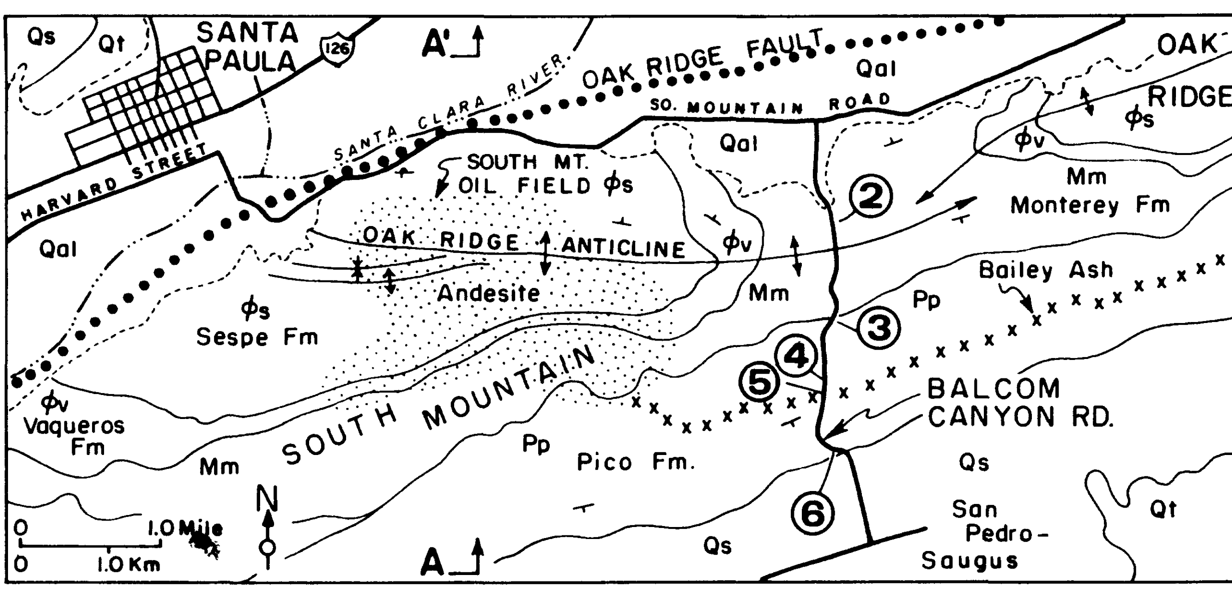


Figure 3. Geologic sketch map of the South Mountain area and Balcom Canyon, Ventura Basin, California. Schematic cross section A-A' is shown on figure 4. See figure 2 for the ages of formations shown on this map; geology modified from Jennings and Troxel (1954).

of coarse terrigenous clastics appear in early Pliocene time representing coalescing submarine fans which advanced from east to west and entered the basin from canyons on the northern and southern margins of the trough (fig. 2). These latter sediments, commonly assigned to the Pico Formation (includes Repetto Formation of some authors), rapidly filled the basin brim full during latest Pleistocene time as accumulation rate exceeded rate of subsidence (fig. 2).

A number of important papers detail aspects of the geology of the Ventura Basin, however, the guidebook by Jennings and Troxel (1954) offers a particularly lucid introduction accompanied by geologic route maps. While ages, paleoenvironmental analyses, and tectonic interpretations of formational units have changed since this latter paper was published the basic geologic framework remains intact. For more recent views on the remarkable tectonic history of the basin the reader is referred to papers by Yeats (1976, 1977).

Biostratigraphy of the Neogene marine sediments of the Ventura Basin continues to be based principally on benthonic Foraminifera with the type areas of Natland's (1952, 1957) Venturian, Wheelerian, and Hallian Stages located along the north flank of the basin. However, Natland (1952) and others (Bandy, 1953; Bandy and Wilcoxon, 1970; Ingle, 1967) have noted that appearances of

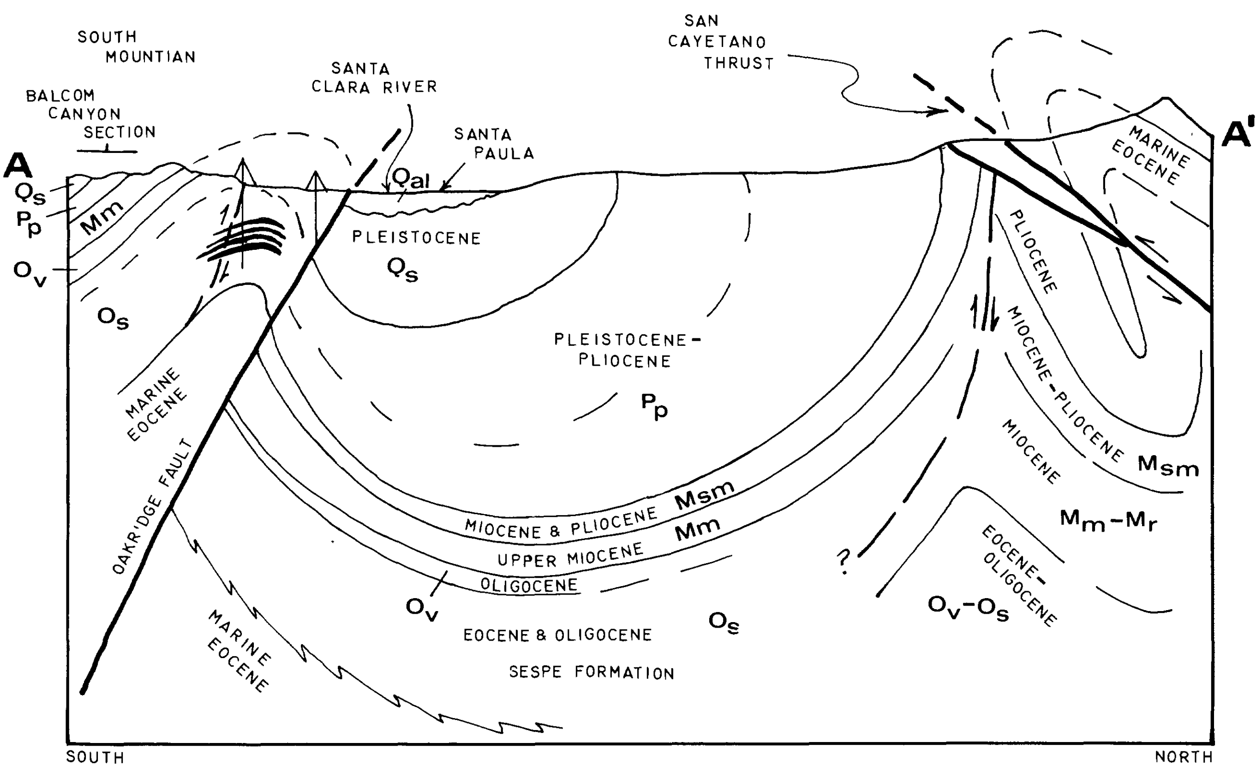


Figure 4. Schematic cross section across the Santa Clara River Valley near Santa Paula, California, illustrating the position of the Balcom Canyon section with respect to the Oak Ridge fault, San Cayetano thrust, and the synclinal trough between these faults; modified from Jennings and Troxel (1954).

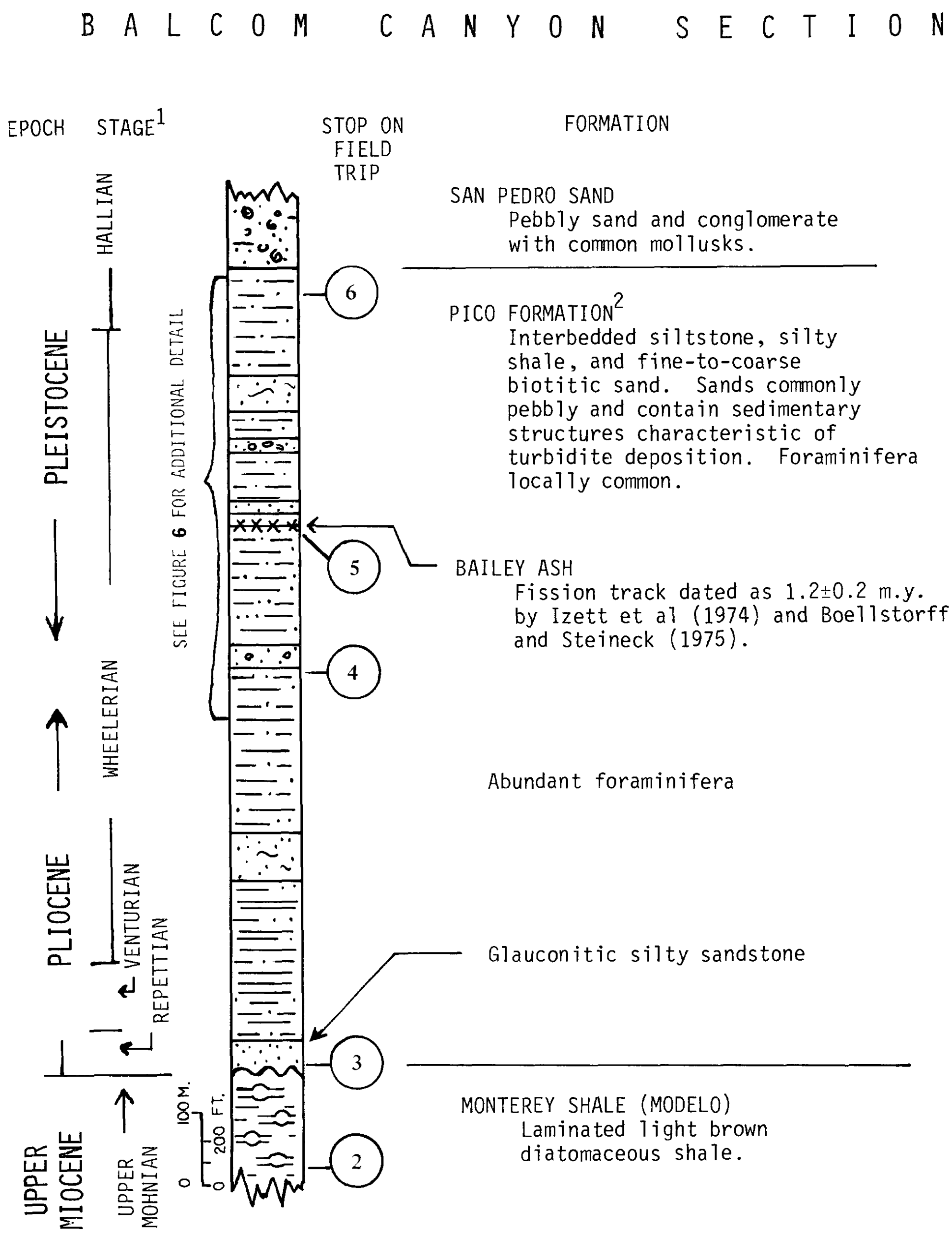
faunas indicative of these stages are commonly controlled by tectonic and sedimentologic history of a given portion of the basin and consequently display pronounced time transgression away from their type areas principally in an east-west direction (Holman, 1958). Analyses of planktonic Foraminifera and calcareous nannofossils in Pliocene and Pleistocene sediments assigned to the Pico, Santa Barbara, and San Pedro Formations (Ingle, 1967; Bandy and Wilcoxon, 1970) also demonstrate this relationship. However, the dominantly subarctic to temperate character of planktonic biofacies within these same sediments dictates only sporadic occurrences of warmer water indices resulting in imprecise placement of the standard Neogene zonal boundaries (fig. 5). This difficulty has been overcome in part through correlation of paleontologically identifiable paleoclimatic events within the California Current province (Ingle, 1977) along with important fission track ages within the Balcom Canyon section (Boellstorff and Steineck, 1976) and recent identification of major paleomagnetic events within Pliocene-Pleistocene strata of the South Mountain area (Blackie and Yeats, 1977).

FIELD TRIP ROUTE

Stop 1 on day two of the IGCP Project 114 field trip is located at the Mission Hills sequence of San Fernando Valley (fig. 1) as discussed by Barron and Ingle (this volume). After leaving the Mission Hills participants travel north on Freeway 5 to Castaic Junction passing through upper Miocene and Pliocene sediments of the eastern Ventura Basin. Turning left at the intersection of Freeway 5 and State Highway 126 travel west along the Santa Clara River Valley which marks the axis of the Ventura Basin (figs. 1 and 3). As noted by Jennings and Troxel (1954) seven en-echelon anticlines form an east-west chain of structures within the Ventura Basin extending for 32 km (20 miles) west along the Oak Ridge uplift which lies south of the Santa Clara River and highway 126 (figs. 1 and 4). The anticlines, from east to west, are named the Oak Ridge, Wiley, Shiells, Bardsdale, South Mountain, and West Mountain--all but Wiley are productive. A north-south schematic cross section across the Santa Clara River Valley at Santa Paula illustrates the relationship of these South Mountain structures to the Oak Ridge fault (fig. 4). Approaching the town of Fillmore from the east South Mountain forms a ridge to the southwest; turn south off highway 126 onto Bardsdale Avenue within Fillmore (fig. 1) then west (left) onto Sespe Street. Travel 0.8 km (0.5 mile) then turn right onto South Mountain; travel 4 km (2.5 miles) and turn left onto Balcom Canyon Road passing into a sequence of north-dipping upper Miocene Monterey (Modelo) shales for 1.6 km (1 mile) to Stop 2 (figs. 1, 3, and 5). A stratigraphic column representing the Balcom Canyon section is presented on figure 5.

STOP 2 - The Monterey Shale (Modelo Formation of some authors) at this location contains an upper Mohnian benthonic foraminiferal fauna along with abundant radiolarian tests indicating deposition at middle bathyal water depths. Volcanic ash beds are also present along with several sandstone dikes.

Travel south on Balcom Canyon Road for 0.8 km (0.5 mile) to Stop 3.



[1]BENTHIC FORAMINIFERAL STAGES OF NATLAND (1952) AND KLEINPELL (1938).

[2]INCLUDES SANTA BARBARA FORMATION OF SOME WORKERS.

Figure 5. Composite stratigraphic column for the Balcom Canyon area, Ventura County, California, showing the position of field stops 2 through 6 in circles; modified from Yeats (1967).

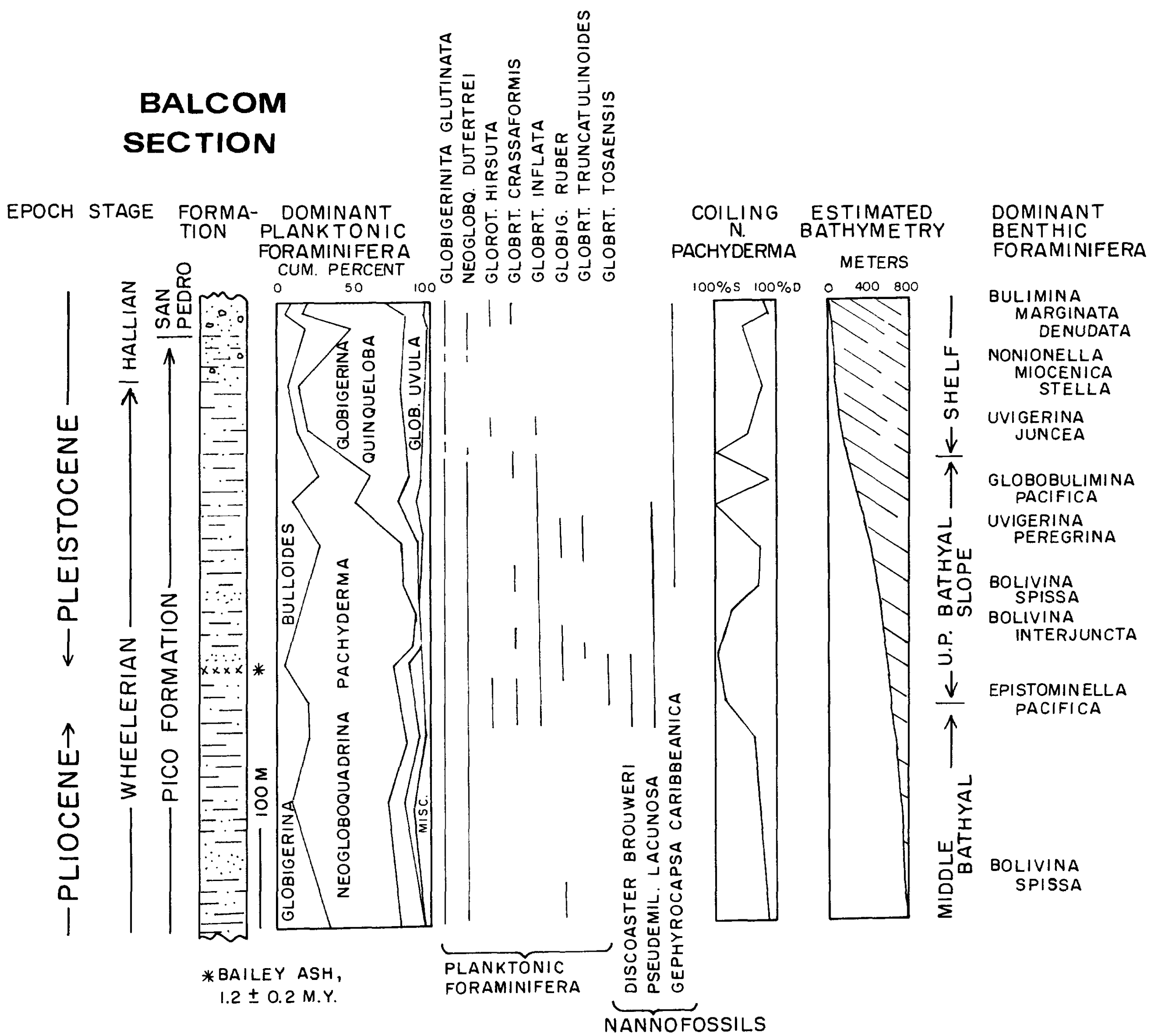


Figure 6. Detailed biostratigraphy, planktonic foraminiferal trends, selected ranges of planktonic Foraminifera and calcareous nannoplankton, and paleobathymetry of the Pliocene and Pleistocene Pico and San Pedro Formations in Balcom Canyon, Ventura County, California. Modified from Ingle (1967) and Bandy and Wilcoxon (1970).

STOP 3 - This location sits astride the Monterey Shale/Pico Formation (Repetto Formation of some authors) contact. The Monterey Shale is unconformably overlain by gray glauconitic sandstones of the Pico unit (fig. 5). Lower bathyal Repettian benthonic Foraminifera including *Bulimina rostrata* and spinose and hispid species of *Uvigerina* are present in these beds along with displaced shallow-water elements. Significantly, diatom floras in the uppermost Monterey Shale in this sequence contain *Thalassiosira oestrupii* (J. A. Barron, personal commun., 1978) indicating this portion of the Monterey Shale is no older than early Pliocene in age contrary to the upper Miocene age commonly applied to these rocks.

Travel south 0.8 km (0.5 mile) to the intersection of Balcom Canyon Road at the Shell Oil Company base road (figs. 3 and 4) and park at Stop 4.

STOP 4 - Upper Pliocene(?) turbidite sands are well displayed within roadcuts at this location. Abundant to common bathyal and middle bathyal Foraminifera are present in these sediments and contain *Bolivina spissa* (fig. 6). Displaced shallow-water molluscan specimens are also present in these beds which along with sedimentary structures indicate downslope transport. Foraminifera from the basal layers of graded sands in this sequence are commonly dominated by displaced neritic species with finer grained sediments in the tops of these bedding units containing *in situ* middle and upper bathyal species (Ingle, 1967).

Travel south and uphill for about 0.2 km (0.1 mile) to Stop 5.

STOP 5 - A prominent white volcanic ash, termed the Bailey Ash, is present in Pico siltstones at this locality. This key lithologic marker bed has been dated by use of fission tracks as 1.2 ± 0.2 m.y. old (Izett, Naeser, and Obradovich, 1974; Boellstorff and Steineck, 1975). Enclosing strata contain well-preserved upper bathyal Wheelerian benthic foraminiferal assemblages indicative of deposition on the shoaling Pliocene-Pleistocene slope.

Cool temperate and subarctic Pliocene-Pleistocene Foraminifera dominated by *Neogloboquadrina pachyderma* occur throughout the upper Pico sequence (fig. 5). Of special significance is the occurrence of rare specimens of *Globorotalia truncatulinoides* and *G. tosaensis* in sediments immediately below the Bailey Ash (fig. 5) suggesting the Pliocene-Pleistocene zone N21/22 boundary is present within this interval. This placement of the Pliocene-Pleistocene boundary is also corroborated by the paleomagnetic work in correlative sediments immediately west of Balcom Canyon where the Jaramillo and Olduvai events were recognized in the Saticoy oil field (Blackie and Yeats, 1976). In addition, Bandy and Wilcoxon (1970) note the discoaster extinction datum just below the Bailey Ash (fig. 5) adding to the evidence for placement of the Pliocene-Pleistocene in the vicinity of the Bailey Ash, a point well below the placement of the provincial Pliocene/Pleistocene boundary at the base of the Hallian Stage (fig. 5).

Continue south and uphill for a distance of 0.8 km (0.5 mile) past the basal conglomeratic sands of the Pleistocene San Pedro Formation to Stop 6 at the top of the Balcom Canyon grade.

STOP 6 - Overview of the Balcom Canyon section (figs. 1 and 3). The San Pedro beds at this location contain neritic mollusks as well as Foraminifera indicative of a shelf environment and the Hallian Stage (fig. 5). Water depths shoaled to less than 100 meters during this phase of the Pleistocene. One of the more interesting trends displayed with this portion of the Balcom Canyon section is the reduction in abundance and diversity of planktonic Foraminifera across the shelf-slope transition identical to patterns seen across the modern shelf off southern California (Ingle, 1967).

A rather complex series of Pliocene-Pleistocene climatic events is recorded in the Pico Formation at Balcom Canyon by significant changes in the coiling patterns of Neogloboquadrina pachyderma with exclusively sinistral subarctic populations present near the Pliocene/Pleistocene boundary similar to patterns associated with this boundary elsewhere in the North Pacific (Ingle, 1977).

STOP 7 - If time permits, participants will retrace the field trip route north down Balcom Canyon and travel northwest to the adjacent town of Santa Paula (fig. 1). We will then turn north on Highway 150 (to Ojai) from the center of Santa Paula and travel up Santa Paula Creek (site of the classic Natland and Kuenen turbidite study) then east between the San Cayetano thrust and Susan fault (fig. 4) to a point 10.7 km (7.5 miles) at Santa Paula where large natural oil seeps are present in Monterey siliceous shales adjacent ot Highway 150 and the historic Ojai oilfield discovered in 1885.

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Balanus gregarius (Conrad), a late Miocene giant barnacle from the Santa Margarita Formation (USNM 254390, USGS loc. M2872).

NEOGENE BIOSTRATIGRAPHY OF THE INDIAN CREEK-SHELL CREEK AREA, NORTHERN LA PANZA RANGE, CALIFORNIA

By W. O. Addicott, R. Z. Poore, J. A. Barron, H. D. Gower,

and Kristin McDougall

A sequence of marine sandstone, shale, and siltstone with minor amounts of diatomite, phosphorite, tuff, and conglomerate is exposed along the northern margin of the La Panza Range, San Luis Obispo County, California (fig. 1). The transition from nonmarine Oligocene clastic rocks through marine sandstone of the Vaqueros Formation and shales of the Monterey Formation to shoreline sandstone of the Santa Margarita Formation represents a depositional cycle typical of the Miocene of the central California Coast Ranges and the Great Valley, to the east. New planktic microfossil and molluscan data from this area can be interrelated with the benthic foraminifer stage sequence of California. These new microfossil data permit correlation of the type section of the Luisian Stage of the California Miocene with oceanic planktic chronologies.

The northern La Panza Range has long been recognized as an excellent reference section for biostratigraphic characterization of parts of the Miocene series in California (Anderson and Martin, 1914). The upper 275 m of the Sandholdt Member of the Monterey Formation in this area forms the type section for the benthic Luisian Stage of Kleinpell (1938). Bivalves and gastropods of the stratigraphically lower Saltos Shale Member of the Monterey Formation and the stratigraphically higher Santa Margarita Sandstone are especially representative of the "Temblor" and "Margaritan" molluscan Stages. Nevertheless, only an early reconnaissance study of "Temblor" Stage mollusks (Anderson and Martin, 1914) and brief accounts of microfossils of the Luisian Stage along Quailwater Creek (Cushman, 1926) and Indian Creek (Smith, 1968; Lipps, 1967) have been published.

Miocene formations are exposed in a north-northwest dipping homoclinal structure (the Highland Monocline of Kleinpell, 1938) that extends some 20 km along the margin of the granitic core of the La Panza Range (fig. 1). These outcrops are bordered on the west by Huerhuero Creek and on the east by Cammatta Creek. The marine section is bounded by Oligocene terrestrial fanglomerate below and by nonmarine gravels and conglomerates of Pliocene and Pleistocene age above.

Geologic maps of the Indian Creek and Shell Creek areas (figs. 2 and 3) are based largely on work by Gower.

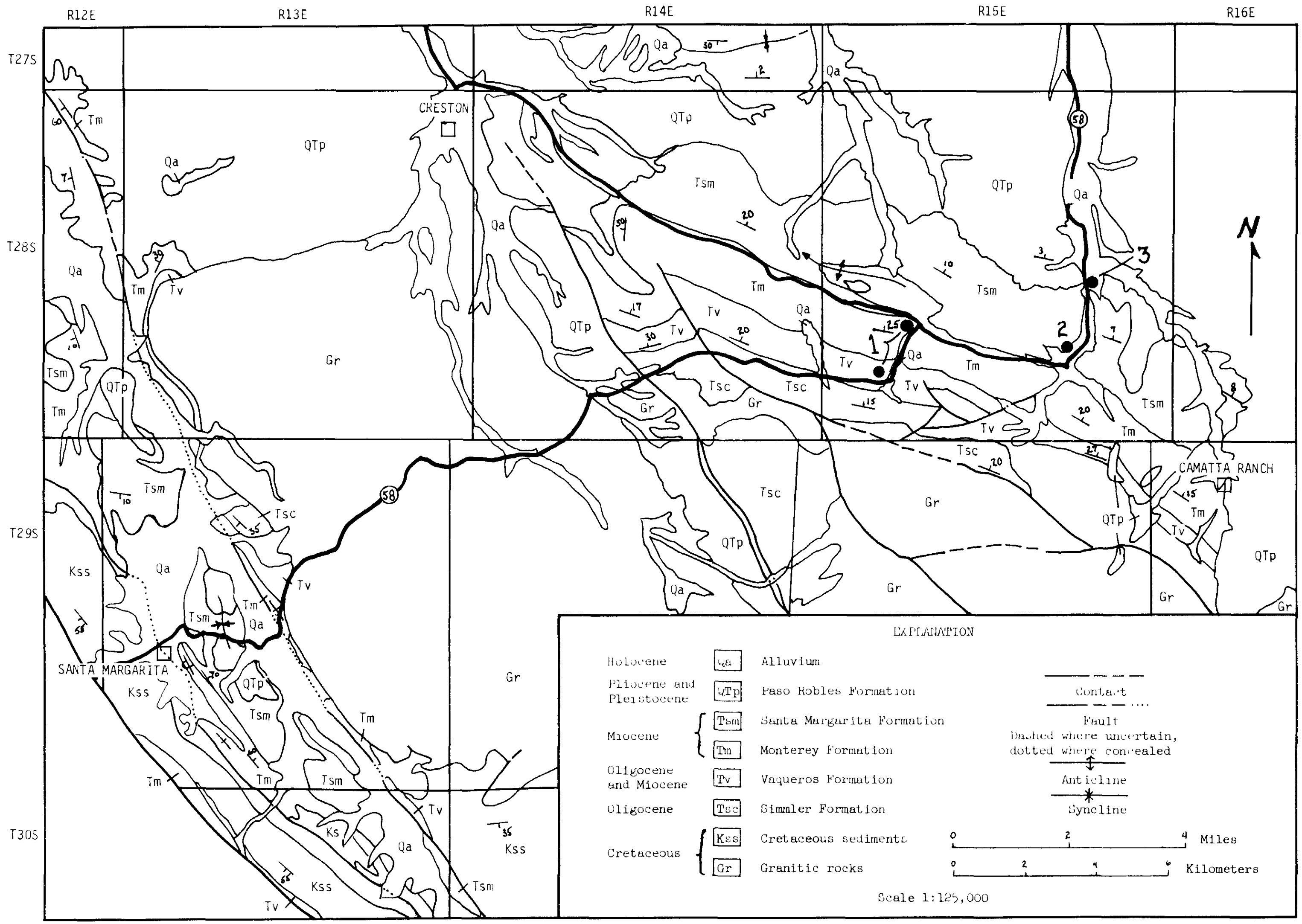

Figure 1. Index map of the northern part of the La Panza Range, San Luis Obispo County, California, showing principal geologic units and field excursion route between Santa Margarita and Cammatta Ranch. Geology modified from Dibblee (1973a).

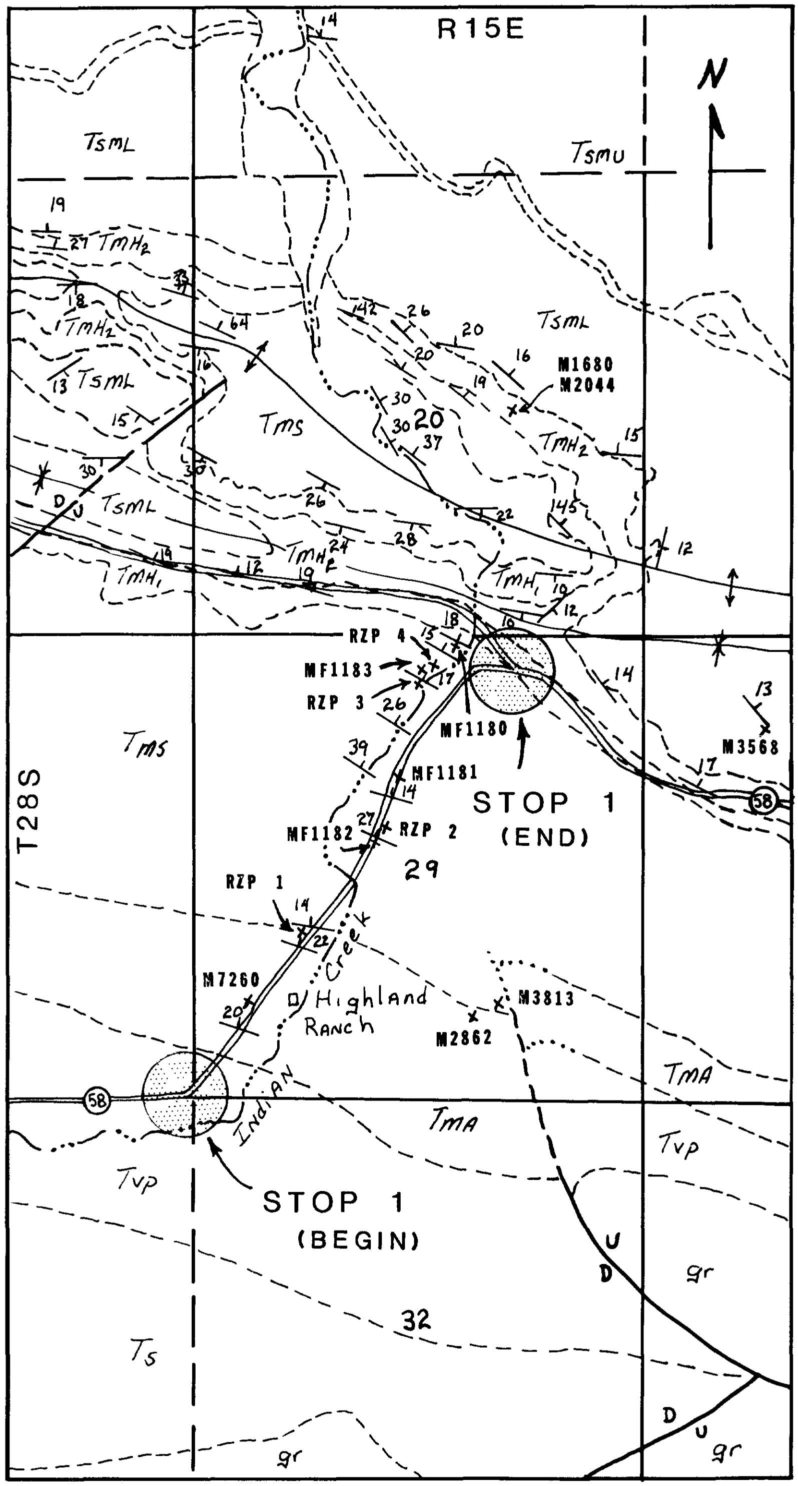

Figure 2. Geologic map of the Indian Creek area, northern margin of the La Panza Range, California, showing fossil localities. See next page for explanation of map units and geologic symbols.

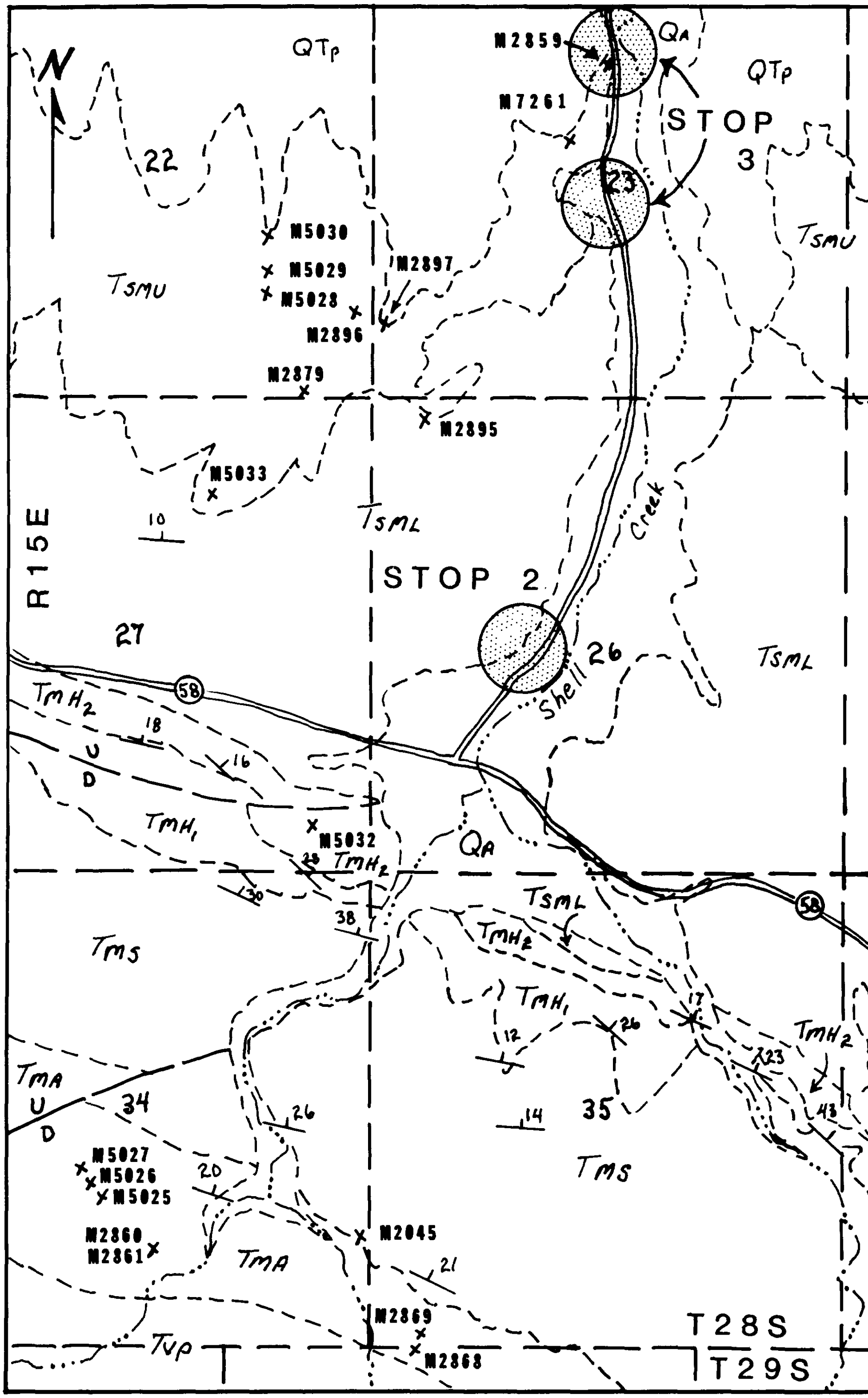

Figure 3. Geologic map of the Shell Creek area, northern margin of the La Panza Range, California, showing fossil localities. See previous page for explanation of map units and geologic symbols.

QUATERNARY
- Holocene
  - Qa — Alluvial deposits
- Pleistocene, Pliocene and Miocene
  - QTp — Paso Robles Formation

TERTIARY
- Miocene
  - Tsmu — Santa Margarita Formation, upper part
  - Tsml — Santa Margarita Formation, lower part
  - Tmh_2 — Hames Member (diatomite) of Monterey Formation
  - Tmh_1 — Hames Member (porcelanite and phosphorite) of Monterey Formation
  - Tms — Sandholdt Member of Monterey Formation
  - Tma — Saltos Shale Member of Monterey Formation
- Oligocene
  - Tvp — Painted Rock Sandstone Member of Vaqueros Formation
- Oligocene(?)
  - Ts — Simmler Formation

CRETACEOUS
- gr — Granitic rocks

Contact
Dashed where approximately located, dotted where concealed.

Fault
Dashed where approximately located, dotted where concealed.

Anticline
Showing trace of axial surface.

Syncline
Showing trace of axial surface.

7

Strike and dip of inclined bed

x Mf1180
Microfossil locality, USGS Menlo Park locality number.

x RZP-1
Microfossil locality, Poore field number

x M2859
Macrofossil locality, USGS Menlo Park locality number

SCALE: 1:24,000

0 — 1 Mile

0 — 1 Kilometer

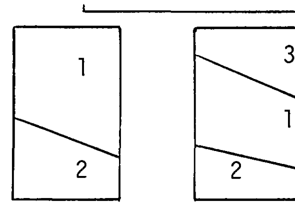

Figure Figure

Source of geology: 1) H. D. Gower, unpublished; 2) T.W. Dibblee (1971, 1973a); 3) D.L. Durham, unpublished.

Explanation of map units and geologic map symbols used in figures 2 and 3

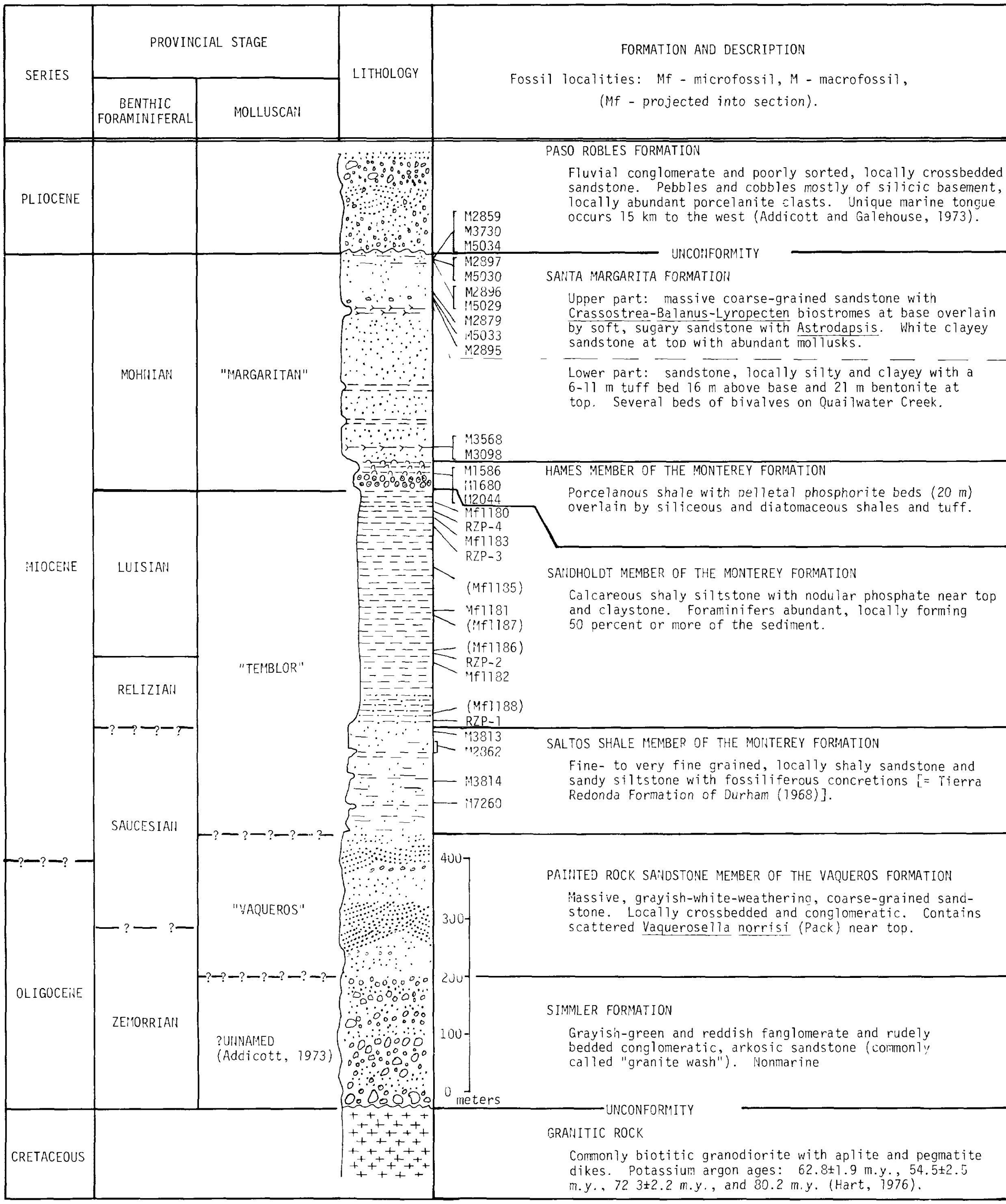

Figure 4. Composite stratigraphic section from the Indian Creek and Shell Creek area, northern La Panza Range, California.

The stratigraphic terminology for this report is based principally on regional geologic mapping by Dibblee (1973a). Most of his Miocene rock units have their type localities in the Cuyama Valley area about 80 km to the southeast. These units can be mapped directly into the Indian Creek-Shell Creek area without interruption. Other formational names from the eastern margin of the Santa Lucia Range, to the northwest, have also been applied to this section (Durham, 1974; Graham, 1976) but that area is separated from the La Panza Range by the Rinconada Fault, a major structural feature along which appreciable right-lateral slip has occurred since the early Miocene (Durham, 1965; Dibblee, 1973b; Hart, 1976).

The principal occurrences of marine fossils are in the Monterey Formation and the overlying Santa Margarita Formation (fig. 4). Mollusks, echinoids, and barnacles are of common occurrence in sandstones in the lower and upper parts of this marine cycle of deposition. Foraminifers, diatoms, and calcareous nannofossils are of common occurrence in the shales and siltstones of the Monterey Formation in the middle part of the sequence.

Poorly stratified nonmarine conglomerate and sandstone included in the Simmler Formation by Dibblee (1973a) unconformably overlies late Mesozoic granitic basement along the northeast margin of the La Panza Range. These varicolored sediments were derived from the underlying basement rock. They are presumed to be of Oligocene age based upon stratigraphic position and similarity to strata exposed along the southeast part of the La Panza Range. The granitic rocks have potassium-argon ages of 62.8 ± 1.8 m.y., 54.5 ± 2.5 m.y., 72.3 ± 2.2 m.y., and 80.2 m.y. (Hart, 1976).

The Painted Rock Sandstone Member of the Vaqueros Formation conformably overlies the Simmler Formation. It consists of coarse-grained, generally white sandstone that is locally crossbedded and pebbly (fig. 5). Some 30 m of coarse-grained sandstone at or near the top of this member contain specimens of the clypeasteroid echinoid *Vaquerosella norrisi* (Pack) (Anderson and Martin, 1914; Kleinpell, 1938).

Abundant and extremely diverse molluscan assemblages occur in concretionary, fine- to very fine grained silty sandstone of the Saltos Shale Member of the Monterey Formation, a 200-m unit exposed in cuts along State Route 58 near Indian Creek and on hillsides between Quailwater Creek and Fernandez Creek, about 9 km to the southeast. Several depositional cycles passing from pebble conglomerate channeled into underlying siltstone into crossbedded sandstone and, finally, to muddy or sandy siltstone are represented in exposures along State Route 58 near the Highland Ranch (Graham, 1976). This unit and the underlying Tertiary sandstones and conglomerates, already discussed, are mapped as Tierra Redonda Formation by Durham (1974). Mollusks from the Saltos (Table 1) are referable to the late early Miocene to middle Miocene "Temblor" Stage and represent the well-known Barker's Ranch fauna (Addicott, 1970) of the southeastern part of the San Joaquin basin, 150 km to the east. Characteristic species include the gastropods *Bruclarkia barkeriana* (Cooper), *Antillophos posunculensis* (Anderson and Martin), *Conus owenianus* Anderson, *Turritella*

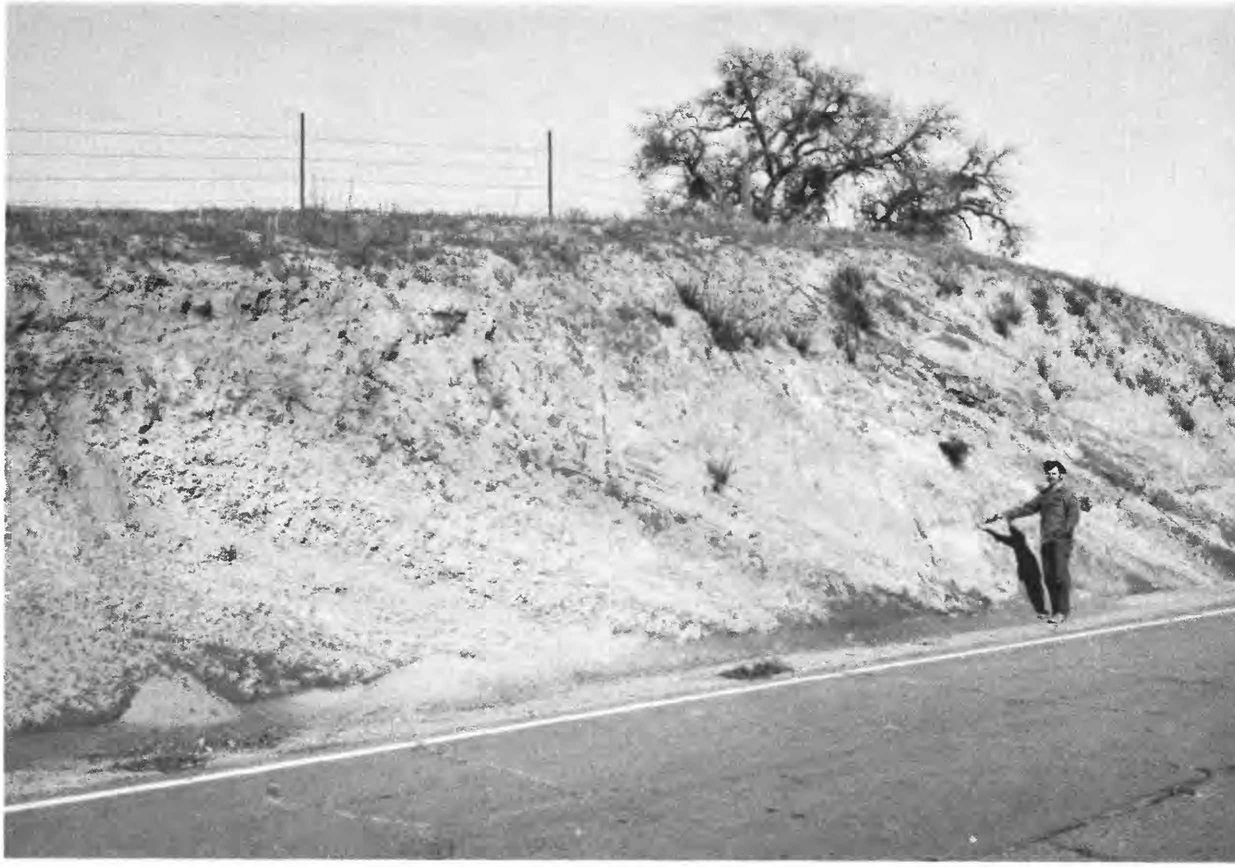

Figure 5. White crossbedded pebbly sandstone in the lower part of the Painted Rock Sandstone Member of the Vaqueros Formation exposed in cut on north side of State Route 58 in the SW1/4 sec. 25, T. 28 S., R. 15 E.

ocoyana Conrad, and T. temblorensis Wiedey, and the bivalves Leptopecten andersoni (Arnold), Solecurtus gabbianus (Anderson and Martin), Tellina wilsoni (Anderson and Martin), and Dosinia margaritana Wiedey (pl. 1). These assemblages suggest deposition in the inner sublittoral (neritic) zone; they may represent storm lag/bar assemblages (Graham, 1976). The presence of many genera now restricted to low latitudes of the eastern North Pacific is indicative of subtropical marine climate. Foraminifers are not recorded from this unit, however a late Saucesian and(or) Relizian age is suggested by the occurrence elsewhere of these "Temblor" Stage mollusks with Saucesian and Relizian benthic foraminifers (Vedder, 1970).

The Sandholdt Member of the Monterey Formation consists of about 425 m of calcareous shale and shaly siltstone with abundant foraminifers. As originally defined in the northwest part of the Salinas basin (Thorup, 1943) this unit directly overlies the Vaqueros Formation and contains some sandy siltstone and concretionary beds in its lower part. The name Sandholdt is here applied to that part of the Monterey Formation that conformably overlies the very fine grained, fossiliferous sandstone of the Saltos Shale Member. Benthic foraminifers from this unit are referable to the Relizian and Luisian Stages of the California microfaunal sequence (Kleinpell, 1938; Smith, 1968, Table 2). Kleinpell (1938) designated a type section for the Luisian Stage in the south limb of a syncline located about 8 km west of Wilson Corner (fig. 1), but foraminifers from this section were not studied. The faunal characterization of the Luisian Stage was based in part on foraminifers from exposures along Quailwater Creek (Cushman, 1926) about 3 km west of Wilson Corner (fig. 1) and the primary faunal data used to define and recognize the Luisian Stage were derived from the benthic foraminifer assemblages of the type Luisian Zones in Reliz Canyon, 140 km to the northwest.

The Relizian/Luisian boundary is recognized in samples from the Sandholdt Member in the type Luisian section (sec. 21, T. 28 S., R. 14 E.) and in road cuts southwest of Wilson Corner (fig. 1). This boundary is marked by the last appearance of Relizian species in or before sample Mf1182. These species include *Cibicides americanus*, *Elphidium granti*, *Lenticulina* cf. *L. miocenica* (*L. miocenica* with raised sutures), and *Uvigerinella obesa impolita*. The Luisian Stage is characterized by the first appearances of *Lenticulina reedi*, *L. smileyi*, and *Valvulineria californica* near this boundary. Also diagnostic of this stage are species listed in figure 6. The lower-middle Luisian "*Valvulineria* flood zone" (abundant specimens of *Valvulineria californica obesa*) occurs in samples Mf1187 and Mf1185. Above this, typical Luisian benthic foraminiferal species appear less frequently because of poor preservation. The upper Luisian is marked by the presence of *Uvigerina joaquinensis* (RZP-4) and the reported occurrence of *Concavella gyroidinaformis* (= *Pulvinulinella gyroidinaformis*) by Smith (1968). The Luisian/Mohnian boundary is not recorded in these assemblages.

The type Luisian Stage assemblages are indicative of the upper bathyal zone (Ingle, 1973). These faunas are dominated by species of the genera *Valvulineria*, *Bolivina* (striated), and *Fursenkoina*. The lower samples (RZP-1, Mf1188, and Mf1182) contain rare, probably transported shelf species of the genera *Elphidium*, *Cibicides*, and *Nonionella*. Samples Mf1186-Mf1185 contain rare, middle and lower bathyal species of *Gyroidina*, *Stilostomella*, and *Bulimina rostrata*. Also *Bolivina tumida* is recorded from these samples suggesting the possibility of lowered oxygen conditions. The upper samples indicate slightly shallower water depths but are still within the upper bathyal zone. Younger assemblages from strata here assigned to the Hames Member identified by Smith (1968) do indicate neritic water depths (< 200 m).

Table 1. Selected macrofossils from Miocene formations of the northern La Panza Range

	SPECIES	FORMATIONS AND LOCALITIES													
MOLLUSCAN STAGE	x - present as identified c - similar form, poor preservation H - highest stratigraphic occurrence in this stage L - lowest stratigraphic occurrence in this stage * - restricted to this stage	Monterey Formation						Santa Margarita Formation							
		M7260	M2862	M3813	M3814	Shell Creek	M1680	M3568	M2895	M2879	M5029	M2896	M5030	M2897	M2859
"TEMBLOR"	Turricula piercei (Anderson and Martin)*					x									
	Panopea abrupta (Conrad)					x		x							
	Tellina piercei (Arnold)[H]					x									
	Solecurtus gabbianus (Anderson and Martin)[H]			x	x	x									
	Neverita andersoni (Clark)			x	x	x									
	Crepidula princeps Conrad			x	x										
	Yoldia supramontereyensis Arnold[L]			x			x								
	Tellina wilsoni Anderson and Martin*		x	x		x									
	Dosinia margaritana projecta Loel and Corey[H]		x			x									
	Turritella moodyi Merriam*		x			x									
	Scaphander jugularis (Conrad)[H]		x			x									
	Turricula piercei Arnold*		c	c		x									
	Trophosycon kernianum (Cooper)		x					x							
	Trophon kernensis Anderson[H]		x	x		x									
	Terebra cooperi Anderson[H]		x			x									
	Oliva californica Anderson[H]		x			x									
	Nassarius arnoldi (Anderson)*		x			x									
	Megasurcula keepi (Arnold)*		x			x									
	Crepidula rostralis Conrad*		x			x									
	Bulla cantuaensis Anderson and Martin		x									x			x
	Bruclarkia barkeriana (Cooper)[H]		x	x	x	x									
	Cancellaria posunculensis Anderson and Martin*		x			x									
	Tresus nuttallii (Conrad)[L]	c				x									
	Spisula albaria (Conrad)	x			c	x									x
	Macoma arctata (Conrad)	x		c		x	x								
	Leptopecten andersoni (Arnold)*	x	x	x		x									
	Dosinia margaritana Wiedey[H]	x				x									
	Chione temblorensis (Anderson)	c			x	x									
	Turricula ochsneri (Anderson and Martin)[H]	c	x												
	Turritella temblorensis Wiedey[H]	x			c	x									
	Turritella ocoyana Conrad[H]	x		x	x	x									
	Conus owenianus Anderson[H]	x	x	c		x									
	Antillophos posunculensis (Anderson and Martin)	x	x	x	x	x									

Table 1. Selected macrofossils from Miocene formations of the northern La Panza Range--continued

MOLLUSCAN STAGE	SPECIES	FORMATIONS AND LOCALITIES													
	x - present as identified c - similar form, poor preservation H - highest stratigraphic occurrence in this stage L - lowest stratigraphic occurrence in this stage * - restricted to this stage	Monterey Formation						Santa Margarita Formation							
		M7260	M2862	M3813	M3814	Shell Creek	M1680	M3568	M2895	M2879	M5029	M2896	M5030	M2897	M2859
"MARGARITAN"	Ostrea vespertina Conrad[L]														x
	Cardita n. sp. aff C. affinis (Sowerby)*														x
	Macoma andersoni Clark*														x
	"Tellina" diabloensis Clark*														x
	Protothaca staleyi (Gabb)[L]														x
	Astraea biangulata (Gabb)[H]														x
	Cerithium cf. C. uncinatum (Gmelin)[L]														x
	Crepidula adunca Sowerby														x
	Trochita spirata (Forbes)														x
	Nassarius cf. N. iniquus (Stewart)[L]														x
	Olivella biplicata Sowerby[L]														x
	Turritella carrisaensis (Anderson and Martin)*														x
	Astrodapsis davisi Grant and Eaton*													x	
	Lyropecten estrellanus (Conrad)												x	x	
	Hinnites giganteus (Gray)												x		
	Astrodapsis tumidus Remond*											x		x	
	Astrodapsis whitneyi Remond*											x			
	Tegula varistriata Nomland* (loc. M2878)														
	Lima vedderi Moore*									x					
	Forreria carisaensis (Anderson and Martin)*								x		x				x
	Crassostrea titan (Conrad)[H]								x		x	x			
	Lyropecten crassicardo (Conrad)[H]								x		x	x			
	Nassarius cf. N. pabloensis (Clark)*							x							
	Macoma indentata Carpenter[L]							x							
	Macoma inquinata (Deshayes)[L]							x							
	Macoma secta (Conrad)							x	x			x			x
	Tellina congesta Conrad*						x								
	Leptopecten discus (Conrad)*						x	x							
	Anadara obispoana (Conrad)[H]						x								

Selected macrofossils from Miocene formations of the northern La Panza Range exposed between Shell Creek and Quailwater Creek. Descriptions of localities, including those not shown on geologic maps, are available at the U.S. Geological Survey, Menlo Park, Calif.

Plate 1

Some characteristic mollusks from the Saltos Shale and Hames Members of the Monterey Formation

Figures 1. *Macoma arctata* (Conrad). USNM 254350, USGS loc. M2044, Hames Member of the Monterey Formation.

2. *Tellina congesta* Conrad. USNM 254351, USGS loc. M1680, Hames Member of the Monterey Formation.

3. *Anadara obispoana* (Conrad). USNM 254352, USGS loc. M1680, Hames Member of the Monterey Formation.

4. *Turricula piercei* (Arnold). USNM 254353, USGS loc. M2862.

5. *Yoldia supramontereyensis* Arnold. USNM 254354, USGS loc. M2044, Hames Member of the Monterey Formation.

6. *Tellina piercei* (Arnold). USNM 254355, USGS loc. M2869.

7. *Trophosycon kernianum* (Cooper). USNM 254356, USGS loc. M2862.

8. *Scaphander jugularis* (Conrad). USNM 254357, USGS loc. M5026.

9. *Leptopecten andersoni* (Arnold). USNM 254358, USGS loc. M5026.

10. *Antillophos posunculensis* (Anderson and Martin). USNM 254359, USGS loc. M3814.

11. *Conus owenianus* Anderson. USNM 254360, USGS loc. M2862.

12. *Turricula wilsoni* (Anderson and Martin). USNM 254361, USGS loc. M2869.

13. *Bruclarkia barkeriana* (Cooper). USNM 254362, USGS loc. M5026.

14. *Turritella temblorensis* Wiedey. USNM 254363, USGS loc. M2869.

15. *Dosinia merriami* Clark. USNM 254364, USGS loc. M5025.

16. *Macoma arctata* (Conrad). USNM 254365, USGS loc. M3814.

17. *Turritella ocoyana* Conrad. USNM 254366, USGS loc. M3814.

18. *Cancellaria posunculensis* Anderson and Martin. USNM 254367, USGS loc. M2868.

19. *Leptopecten andersoni* (Arnold). USNM 254368, USGS loc. M5026.

20. *Dosinia margaritana projecta* Loel and Corey. USNM 254369, USGS loc. M5025.

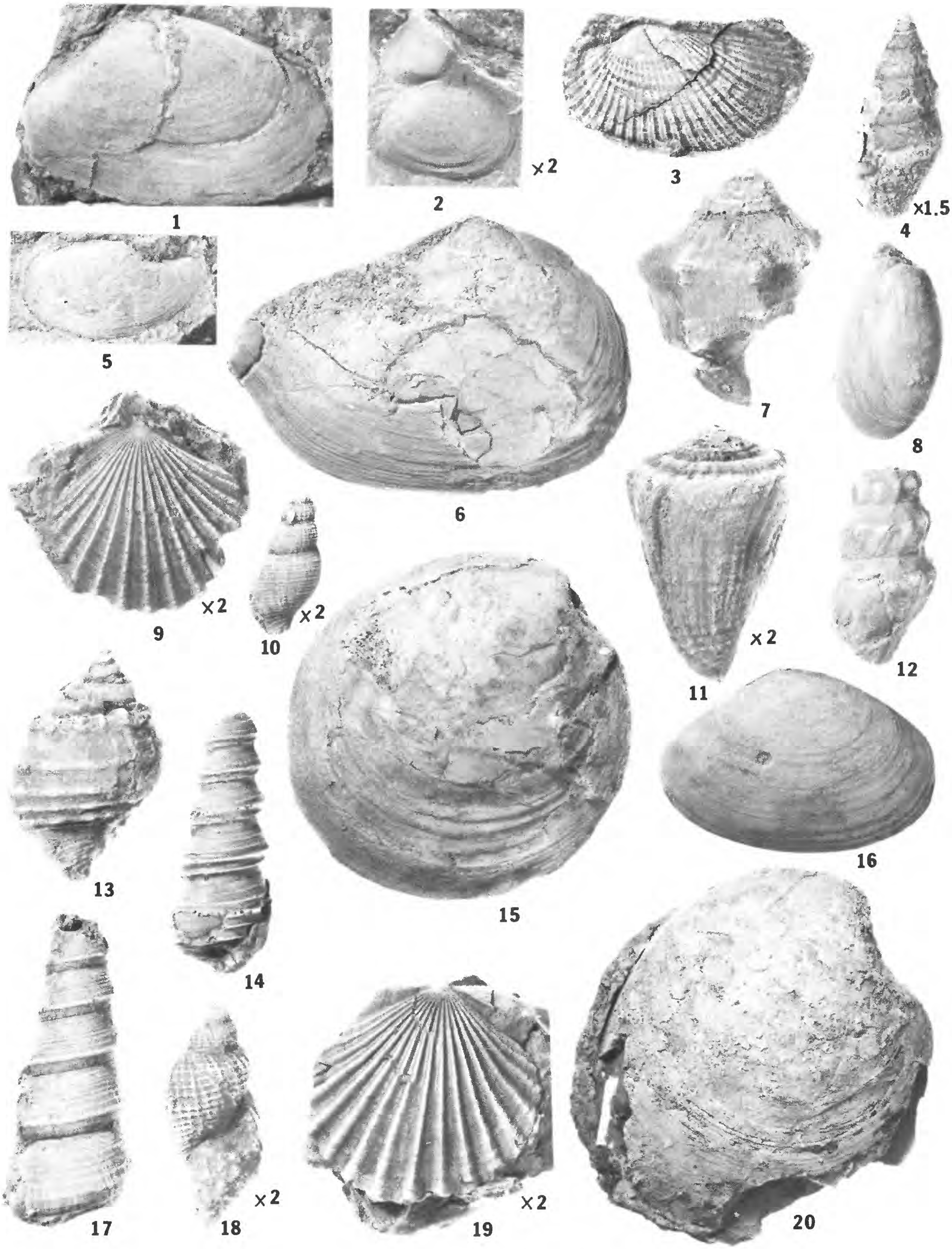
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Table 2. Benthic foraminifers from the Sandholdt Member of the Monterey Formation.

SPECIES A, abundant; C, common; F, few; R, rare ?, questionable occurrence	LOCALITY RZP-1	Mf1188	Mf1182	RZP-2	Mf1186	Mf1187	Mf1185	RZP-3	Mf1183	RZP-4	Mf1180
Bolivina advena	A	A	A	-	-	-	-	-	-	-	-
Bolivina marginata	C	-	-	-	C	-	-	-	-	-	-
Lenticulina cf. *L. miocenica*	C	-	-	-	-	-	-	-	-	-	-
Lenticulina reedi	F	F	-	-	F	F	F	-	-	-	-
Lenticulina smileyi	R	F	-	F	F	F	A	-	F	R	-
Nonionella costifera	C	F	-	-	C	F	C	R	-	F	F
Plectofrondicularia miocenica	F	F	-	-	-	-	-	-	-	-	-
Uvigerinella californica	A	A	-	-	C	-	C	-	-	-	-
Uvigerinella obesa	A	C	-	-	-	R	R	-	-	-	-
Uvigerinella obesa impolita	A	-	R	-	-	-	-	-	-	-	-
Valvulineria costasensis	A	-	-	-	-	-	-	-	-	-	-
Baggina californica	-	C	-	-	-	-	-	-	-	-	-
Baggina robusta	-	A	-	-	C	-	F	-	-	-	-
Bolivina advena striatella	-	A	A	C	-	-	-	-	F	A	F
Bolivina californica	-	C	-	-	C	-	F	F	-	-	-
Cancris sagra	-	C	-	-	-	-	R	-	-	-	-
Cassidulina pulchella	-	R	-	-	-	-	R	-	-	F	-
Cibicides americanus	-	F	-	-	-	-	-	-	-	-	-
Elphidium granti	-	R	-	-	-	-	-	-	-	-	-
Epistominella subperuviana	-	F	R	F	F	F	F	-	-	-	-
Fursenkoina bramletti	-	F	-	-	-	-	-	-	-	-	-
Globocassidulina subglobosa	-	F	-	-	-	-	-	-	-	-	-
Gyroidina soldanii	-	F	-	-	F	-	F	-	-	R	-
Lagena sp.	-	R	-	-	-	-	-	-	-	-	-
Lenticulina mayi	-	F	-	-	R	-	-	-	-	-	-
Marginulina beali	-	F	-	-	C	C	C	-	-	-	-
Nodosaria sp.	-	F	-	-	-	-	-	-	-	-	-
Orthomorphina rohri	-	F	-	-	-	-	-	-	-	-	-
Pullenia multilobata	-	R	-	-	-	-	-	-	-	-	-
Siphogenerina branneri	-	F	-	-	F	C	A	-	-	-	-
Uvigerina cf. *U. kernensis*	-	F	-	-	F	-	-	-	-	-	-
Valvulineria californica	-	A	C	C	A	A	A	C	-	F	-
Valvulineria depressa	-	F	-	-	-	-	F	-	-	-	?
Fursenkoina californiensis	-	-	R	F	F	A	C	A	-	-	C
Bolivina salinasensis	-	-	-	F	C	A	F	A	C	-	-
Valvulineria miocenica	-	-	-	C	-	-	F	-	F	A	-
Anomalina salinasensis	-	-	-	-	R	-	-	-	-	-	-
Baggina robusta globosa	-	-	-	-	R	-	-	-	-	-	-
Bolivina marginata adelaidana	-	-	-	-	A	A	C	C	A	F	-
Bolivina tumida	-	-	-	-	C	R	-	-	-	-	-
Buliminella curta	-	-	-	-	C	F	C	A	A	-	-
Buliminella subfusiformis	-	-	-	-	A	A	F	-	-	-	-
Cassidulina crassa	-	-	-	-	F	F	F	-	-	-	-
Dentalina obliqua	-	-	-	-	F	-	F	-	-	-	-
Marginulina subbullata	-	-	-	-	R	-	R	-	-	-	-
Nonionella miocenica	-	-	-	-	F	F	-	C	-	-	-
Pullenia miocenica	-	-	-	-	R	-	C	F	-	-	-
Stilostomella lepidula	-	-	-	-	R	-	-	-	-	-	-
Bulimina pseudotorta	-	-	-	-	-	R	R	-	-	-	-
Chilostomella ovoidea	-	-	-	-	-	R	-	-	-	-	-
Planularia sp.	-	-	-	-	-	R	F	-	-	-	-
Trifarina cf. *T. occidentalis*	-	-	-	-	-	F	R	-	R	-	-
Valvulineria californiensis obesa	-	-	-	-	-	A	A	-	A	-	-
Bolivina dunlapi	-	-	-	-	-	-	F	-	-	-	-
Bulimina rostrata	-	-	-	-	-	-	R	-	-	-	-
Frondicularia foliacea	-	-	-	-	-	-	F	-	-	-	-
Marginulina dubia	-	-	-	-	-	-	F	-	-	-	-
Bulimina ovula	-	-	-	-	-	-	-	-	F	-	-
Uvigerina joaquinensis	-	-	-	-	-	-	-	-	-	F	-
Benthic Foraminiferal Stage	RELIZIAN			LUISIAN							

Occurrence of selected planktic microfossils in samples from the type section of the Luisian Stage and from the Sandholdt Member exposed along the road southwest of Wilson Corner are shown in table 3. The nannofossil assemblage from RZP-2 is referable to the *Helicosphaera ampliaperta* Zone and nannofossil assemblages from Mf1186 through RZP-3 are referable to the *Sphenolithus heteromorphus* Zone. Nannofossils from RZP-1 are too sparse for reliable zone assignment and the assemblage from RZP-4 (a and b) could represent the *Sphenolithus heteromorphus* Zone or the *Discoaster exilis* Zone. Planktic foraminifers from samples up through RZP-3 (pls. 2 and 3) are indicative of Zones N 7 through N 9 of Blow (1969). Following the correlation of nannofossil and foraminifer zones of Ryan and others (1975), RZP-2 and Mf1186 are assigned to Zone N 8 and the other samples to Zone N 9. Diatoms in Mf1186 and Mf1185 are assigned to the *Denticula lauta* Zone. Koizumi (1977) estimates the upper boundary of this zone to be 14.0 m.y. BP or within the middle part of the middle Miocene of Ryan and others (1975). *Annellus californicus* Tempere, reported in Mf1186, has a short range which encompasses the *Orbulina* Datum (the Zone N 8 / Zone N 9 boundary) (Opdyke and others, 1974). Thus the diatom data from samples Mf1186 and Mf1185 show close agreement with the stratigraphic assignment suggested by the calcareous plankton.

Planktic zone assignments and position of the type Luisian Stage are shown on figure 6. The base of the type Luisian is within the *Helicosphaera ampliaperta* Zone and thus the base of the Luisian in its type area correlates approximately with the base of the middle Miocene or Langhian (Ryan and others, 1975).

The highest part of the Monterey Formation in this area is included in the Hames Member named by Durham (1974) for siliceous shale located along the west side of the Salinas Valley about 65 km to the north. Near Wilson Corner, the basal 21 m of the Hames Member consist of porcelaneous shale with several beds of pelletal phosphorite and these phosphorite beds were used by Kleinpell (1938) to define the upper limit of the Luisian Stage. The upper 24 m of the Hames Member along Indian Creek consist of siliceous shale, diatomaceous shale, and bentonite. The diatomaceous strata at the top of the Monterey Formation compare closely, in lithology and stratigraphic position, to the Buttle Member (Mandra, 1960; Durham, 1968) of the western margin of the Salinas basin farther to the north. Diatoms from the Indian Creek section are referable to the *Denticula hustedtii* - *D. lauta* Zone of Koizumi (1975) and North Pacific Diatom Zone XIX as used by Barron (1976) (table 3 and fig. 6). At Upper Newport Bay in southern California, strata containing diatom assemblages of these zones are assigned to the lower Mohnian Stage of Kleinpell (1938) (Barron, 1976). The upper siliceous and diatomaceous part of the Monterey Formation in the Indian Creek area was considered Mohnian in age by Kleinpell (1938, figs. 6, 14) presumably because of its stratigraphic position above the type Luisian. Smith (1968), however, assigned this part of the Monterey Formation to the Luisian Stage because of the occurrence of *Valvulineria californica* Cushman, a form considered diagnostic of the Luisian. This interpretation is based on a single sample (G194, Smith, 1968), which is located several miles west of the area considered and is associated with a fault. Reexamination of the fauna indicates that it is biostratigraphically and paleoecologically incompatible with faunas placed stratigraphically adjacent to it. It is therefore probable that the sample is

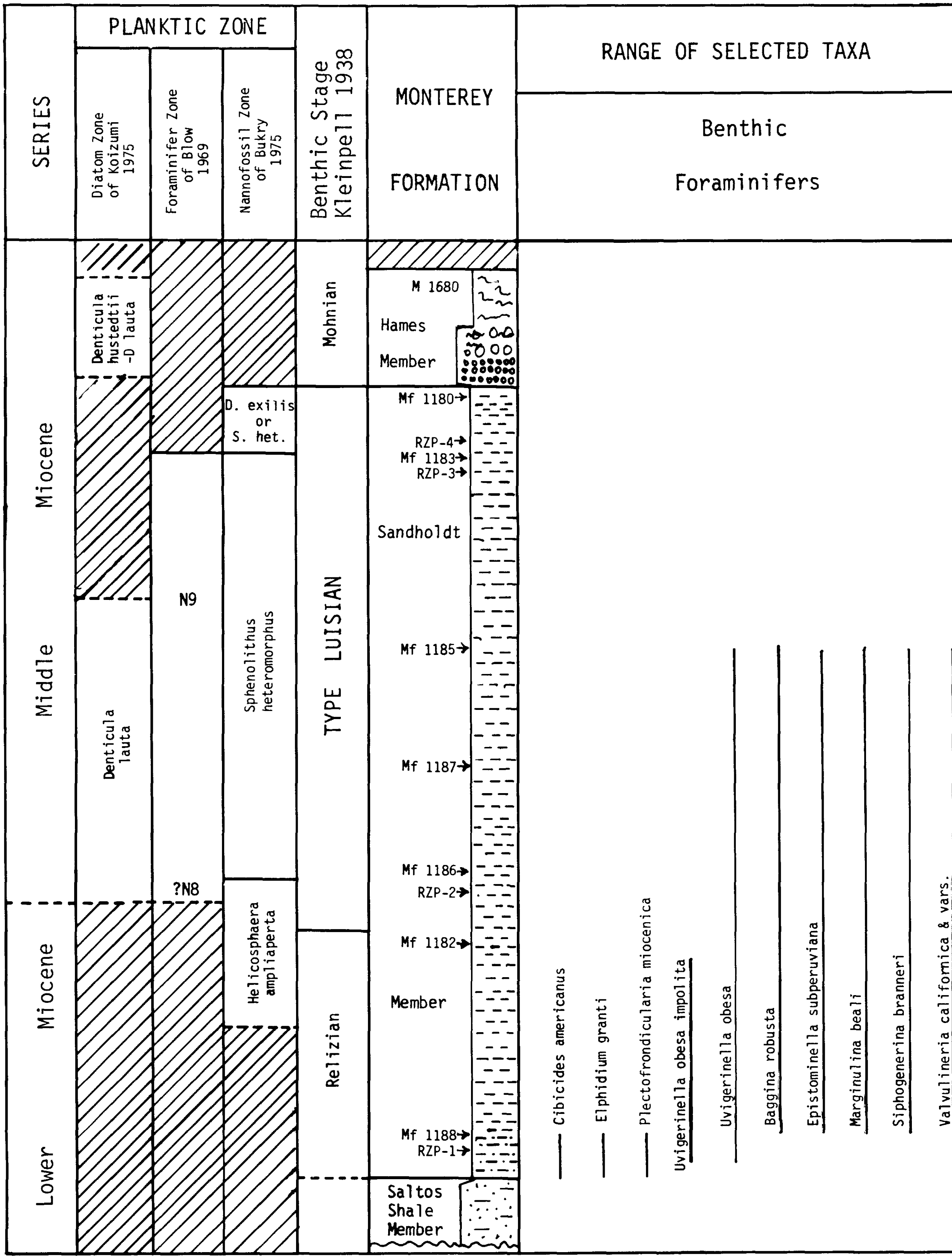
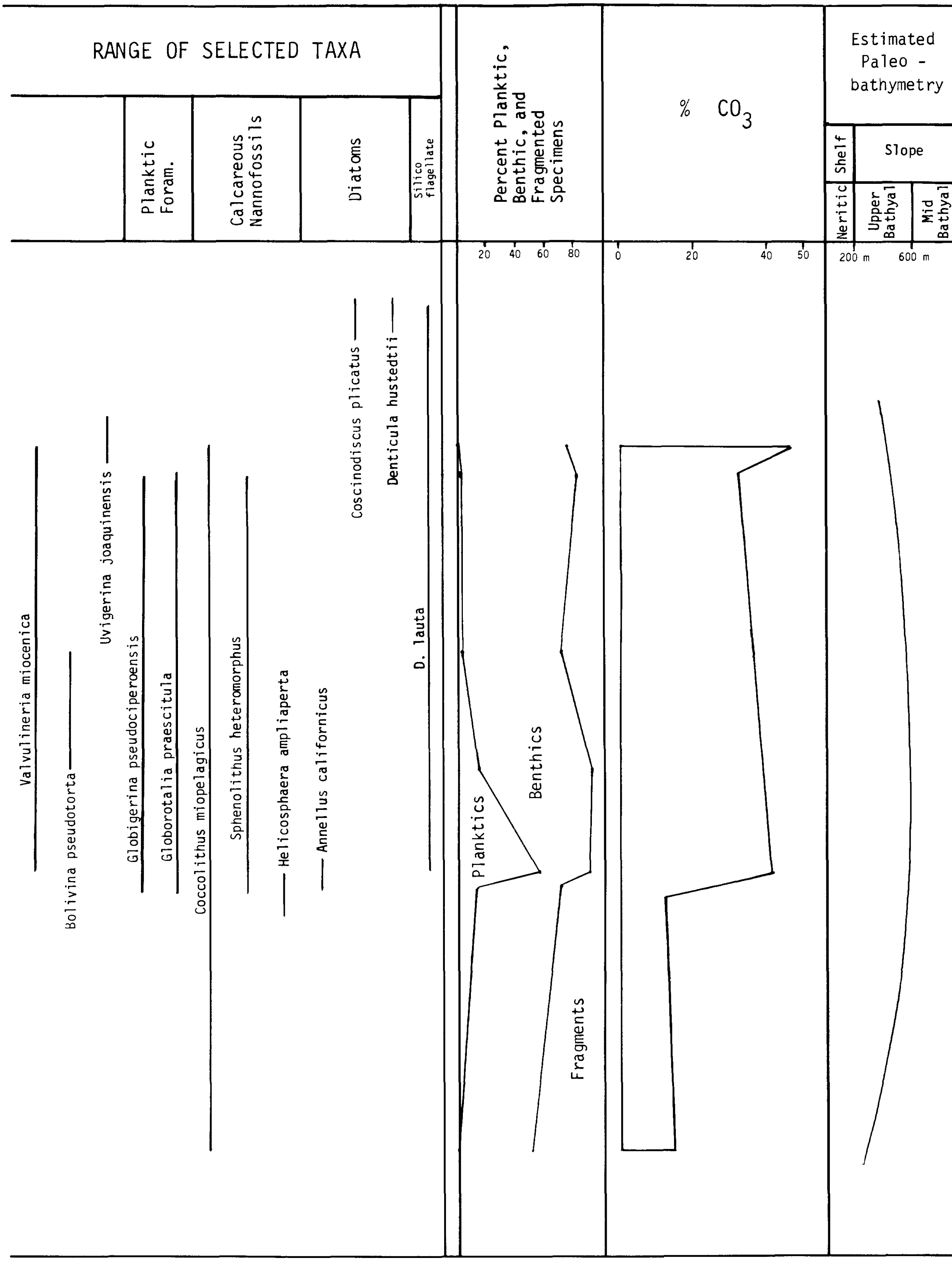


Figure 6. Planktic zone assignments, percentage of planktic foraminifers,



and percentage of carbonate in samples from the Sandholdt Member.

Table 3. Occurrence of selected planktic microfossils in the Sandholdt Member of the Monterey Formation.

RZP-1	RZP-2	Mf1186	Mf1187	Mf1185	RZP-3	RZP-4 a & b	SAMPLE / TAXON	
-	x	x	-	x	x	-	*Globigerina angustiumbilicata* Bolli	PLANKTIC FORAMINIFER
-	x	x	x	x	x	x	*G. bulloides* d'Orbigny (s.l.)	PLANKTIC FORAMINIFER
-	x	x	x	-	x	-	*G. obesa* (Bolli)	PLANKTIC FORAMINIFER
-	x	x	x	x	x	-	*G. pseudociperoensis* Blow	PLANKTIC FORAMINIFER
-	x	-	-	-	-	-	*G. woodi* Jenkins	PLANKTIC FORAMINIFER
-	-	x	-	x	-	-	*Globigerinita glutinata* (Egger)	PLANKTIC FORAMINIFER
-	x	x	-	-	-	-	*Globigerinoides trilobus* (Reuss) (s.l.)	PLANKTIC FORAMINIFER
-	-	x	-	-	-	-	*Globoquadrina altispira* (Cushman and Jarvis)	PLANKTIC FORAMINIFER
-	x	-	-	-	-	-	*Globorotalia* aff. *G. birnageae* Blow	PLANKTIC FORAMINIFER
-	x	x	x	x	x	x	*G. minutissima* Bolli	PLANKTIC FORAMINIFER
-	x	-	-	-	-	-	*G.* aff. *G. peripheroronda* Blow and Banner	PLANKTIC FORAMINIFER
-	x	x	x	-	x	-	*G. praescitula* Blow	PLANKTIC FORAMINIFER
-	-	x	x	-	x	-	*G. zealandica* Hornibrook	PLANKTIC FORAMINIFER
-	x	x	-	-	x	x	*Turborotalita quinqueloba* (Natland) (s.l.)	PLANKTIC FORAMINIFER
x	-	x	-	x	x	x	*Coccolithus miopelagicus* Bukry	CALCAREOUS NANNOFOSSIL
x	x	x	-	x	x	x	*C. pelagicus* (Wallich) Schiller	CALCAREOUS NANNOFOSSIL
-	x	x	-	x	x	x	*Cyclicargolithus floridanus* (Roth and Hay) Bukry	CALCAREOUS NANNOFOSSIL
x	x	x	-	x	-	-	*Discoaster deflandrei* Bramlette and Riedel	CALCAREOUS NANNOFOSSIL
-	x	x	-	x	x	-	*D. exilis* Martini and Bramlette	CALCAREOUS NANNOFOSSIL
-	x	-	-	-	-	-	*Helicosphaera ampliaperta* Bramlette and Wilcoxon	CALCAREOUS NANNOFOSSIL
-	x	x	-	x	x	x	*H. carteri* (Wallich) Kamptner	CALCAREOUS NANNOFOSSIL
-	x	x	-	x	x	-	*Sphenolithus heteromorphus* Deflandre	CALCAREOUS NANNOFOSSIL
-	-	x	-	x	-	-	*Actinocyclus ingens* Rattray	SILICOFLAGELLATE: DIATOM
-	-	x	-	-	-	-	*Annellus californicus* Tempere	SILICOFLAGELLATE: DIATOM
-	-	x	-	-	-	-	*Coscinodiscus lewisianus* Greville	SILICOFLAGELLATE: DIATOM
-	-	x	-	x	-	-	*Denticula lauta* Bailey	SILICOFLAGELLATE: DIATOM
-	-	x	-	x	-	-	*Synedra jouseana* Sheshukova-Poretzkaya	SILICOFLAGELLATE: DIATOM
-	-	x	-	x	-	-	*Corbisema triacantha* (Ehrenberg) Hanna	SILICOFLAGELLATE

mislocated in the section or was mislabeled and is more appropriately placed with the lower Luisian samples. Benthic foraminifer assemblages were considered by Smith (1968) to indicate deposition in depths of less than 45 m and associated mollusks (USGS locs. M1680 and M2044) also suggest inner sublittoral depths. A contrasting view is that the benthic foraminifers, and presumably the mollusks, are displaced from shallow water and that the entire Hames Member of this area represents depths of more than 1,000 m (Graham, 1976).

Conformably overlying the Monterey Formation is the Santa Margarita Formation, a predominately shoreline to shallow subtidal deposit varying from about 290 m to 425 m in thickness. A 6- to 10-m tuff bed occurs about 15 m above the base of the formation. Unpublished research by D. L. Durham (written commun., 1978) indicates that the Santa Margarita can be divided into two members. The rather poorly exposed lower member comprises about two-thirds of the thickness of the Santa Margarita. The top of this member is marked by a 21-m siliceous shale in the area between Shell Creek and Indian Creek. The basal part of the upper member consists of massive, coarse- to very coarse grained sandstone that contains dense accumulations of the giant oyster Crassostrea titan (Conrad), scattered echinoids with raised petals (Astrodapsis spp.), the giant barnacle Balanus (Tamiosoma) gregarius (Conrad), and the giant scallop Lyropecten crassicardo (Conrad) (pl. 4). This is a typical Santa Margarita faunal assemblage; the concurrent ranges of these species is diagnostic of the "Margaritan" Stage. Benthic foraminifers are of very shallow water aspect and are referable to the middle to late Miocene Mohnian Stage (Kleinpell, 1938; Smith, 1968).

Nonmarine cobble and pebble conglomerate and sandstone of the Paso Robles Formation unconformably overlie the Santa Margarita Formation. Clasts in the Quailwater Creek to Cammatta Creek area are dominantly of silicic basement rock (Galehouse, 1967) although farther west the dominant clast lithology is porcellanite. The Paso Robles is almost entirely a nonmarine unit although reworked mollusks from the Santa Margarita Formation occur locally in the Paso Robles. A small assemblage of autochthonous mollusks of Pliocene age occurs in the lower part of the Paso Robles Formation about 15 to 20 km to the west of Indian Creek (Addicott and Galehouse, 1973).

Plate 2

Planktic foraminifers from the Sandholdt Member of the Monterey Formation.
Scale bar = 100 um for all illustrations.

Figure 1, 2. *Globigerina bulloides* d'Orbigny (s.l.).
1. Umbilical view, sample Mf1187.
2. Spiral view, sample Mf1187.

3, 6. *Globigerina pseudociperoensis* Blow.
3. Umbilical view, sample Mf1187.
6. Spiral view, sample Mf1187.

4, 5. *Globigerinoides trilobus* Reuss (s.l.).
4. Umbilical view, sample Mf1186.
5. Spiral view, sample Mf1186.

7-9. *Globigerina obesa* (Bolli).
7. Umbilical view, sample Mf1186.
8. Side view, sample Mf1186.
9. Spiral view, sample Mf1186.

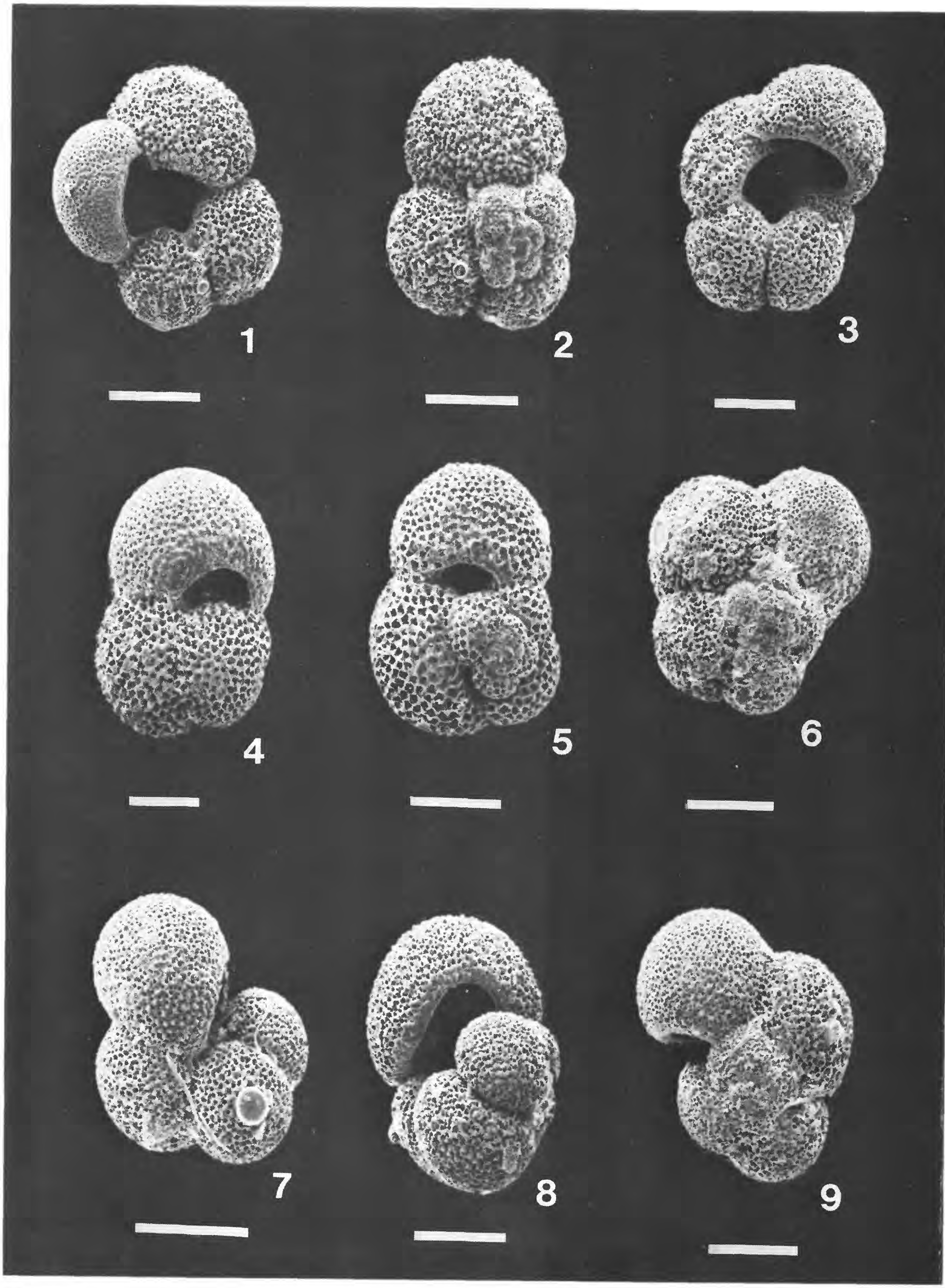

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Plate 3

Planktic foraminifers from the Sandholdt Member of the Monterey Formation. Scale bar = 100 um for figures 1-7 and 30 um for 8 and 9.

Figures 1-3. *Globorotalia praescitula* Blow.
1. Umbilical view, sample Mf1186.
2. Side view, sample Mf1186.
3. Spiral view, sample Mf1186.

4, 5. *Globigerina woodi* Jenkins.
4. Umbilical view, sample RZP-2.
5. Spiral view, sample RZP-2.

6. *Globigerina angustiumbilicata* Bolli.
Umbilical view, sample RZP-2.

7. *Globoquadrina altispira* (Cushman and Jarvis).
Umbilical view, sample Mf1186.

8, 9. *Globorotalia minutissima* Bolli.
8. Umbilical view, sample RZP-2.
9. Spiral view, sample RZP-2.

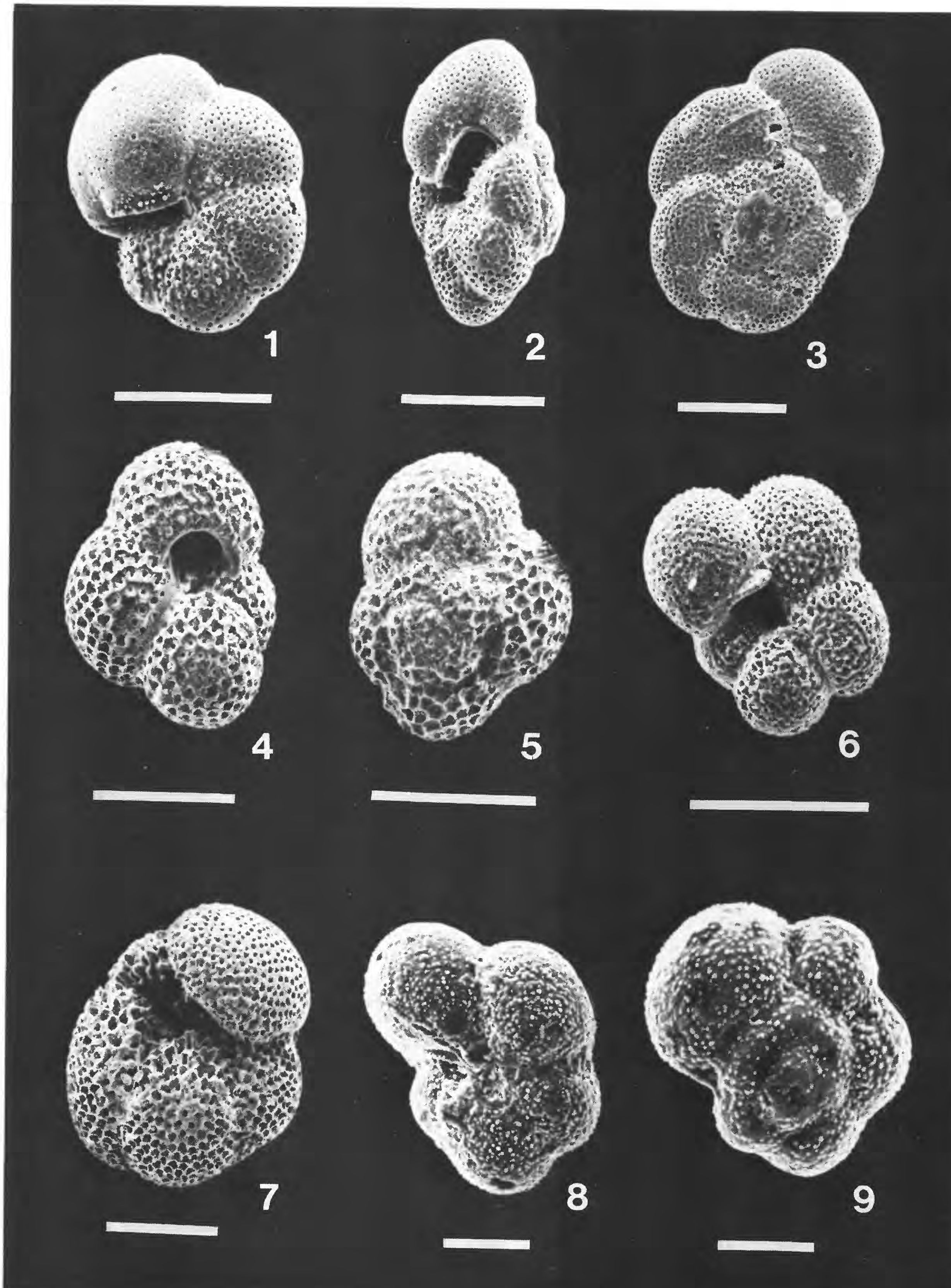
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Plate 4

Some characteristic mollusks and echinoids from the Santa Margarita Formation.

Figures 1. *Cardita* n. sp. aff. *C.* *affinis* (Sowerby). USNM 254370, USGS loc. M2859.

2. *Astraea biangulata* (Gabb). USNM 254371, USGS loc. M2859.

3. *Bulla cantuaensis* Anderson and Martin. USNM 254372, USGS loc. M2859.

4. *Protothaca staleyi* (Gabb). USNM 254373, USGS loc. M5034.

5. *Tegula varistriata* Nomland. USNM 254374, USGS loc. M2878.

6, 7. *Astrodapsis tumidus* Remond. USNM 254375, USGS loc. M3735 (6 X 1-1/2).

8. *Forreria* n. sp.? USNM 254376, USGS loc. 4930.

9, 10. *Astrodapsis whitneyi* Remond. USNM 254377, USGS loc. M2872.

11. *Lyropecten estrellanus* (Conrad). USNM 254378, USGS loc. M2872.

12. *Forreria carisaensis* (Anderson). USNM 254379, USGS loc. M2382.

13. *Trophosycon kernianum* (Cooper). USNM 254380, USGS loc. M3568.

14. *Turritella carrisaensis* (Anderson and Martin). USNM 254381, USGS loc. M2834.

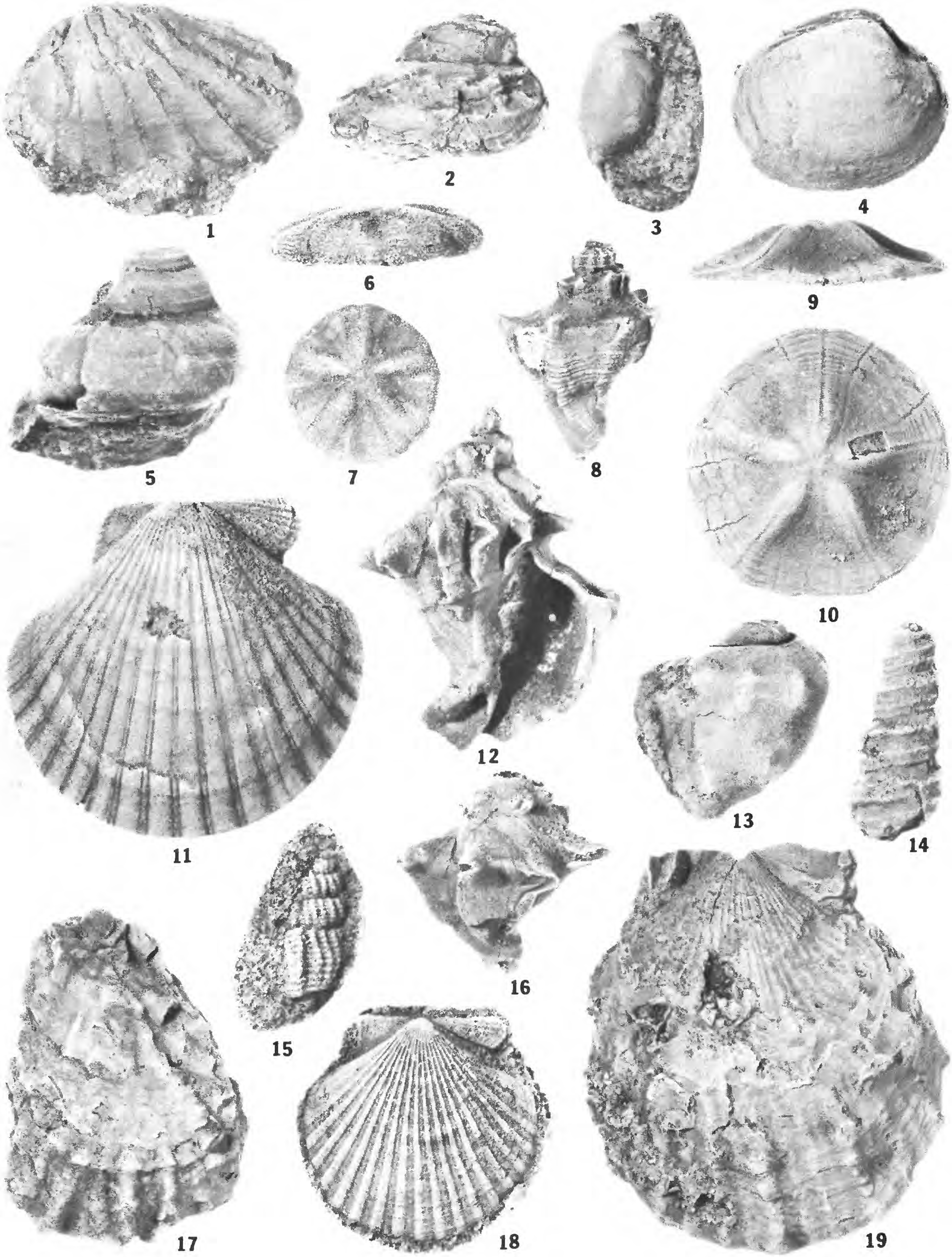
15. *Nassarius* cf. *N.* *pabloensis* (Clark). USNM 254382, USGS loc. M3568.

16. *Forreria carisaensis* (Anderson). USNM 254383, USGS loc. 4930.

17. *Ostrea vespertina* Conrad. USNM 254384, USGS loc. M2872.

18. *Leptopecten discus* (Conrad). USNM 254385, USGS loc. M3568.

19. *Hinnites giganteus* (Gray). USNM 254386, USGS loc. M2857.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STOP 1. SALTOS SHALE, SANDHOLDT, AND HAMES MEMBERS OF THE MONTEREY FORMATION.

A stroll northward along State Route 58 for approximately 1.5 km to examine and sample road cut and stream bed exposures of the Saltos Shale, Sandholdt, and Hames Members of the Monterey Shale. The bus will unload in the uppermost part of the Painted Rock Sandstone Member of the Vaqueros Formation which, unfortunately, is not exposed in the immediate vicinity. The first two road cuts (fig. 7) expose about 75 m of silty fine- to very fine grained sandstone of the Saltos Shale Member. Molds of articulated bivalves and small, ornate gastropods occur in storm lag deposits in both outcrops (USGS loc. M7260 is in the lower part of the northern outcrop). Continuing northward past the small southeast-trending gully at Highland Ranch, the third (and longest) cut along Route 58 exposes Saltos Shale Member in the lower part and Sandholdt Member in the upper part (fig. 7). The contact between these units is not well exposed, generally it is recognized at the highest occurrence of very fine grained concretionary silty sandstone that commonly contains orange-colored concretions. Foraminifer locality RZP-1 in the basal part of the Sandholdt is

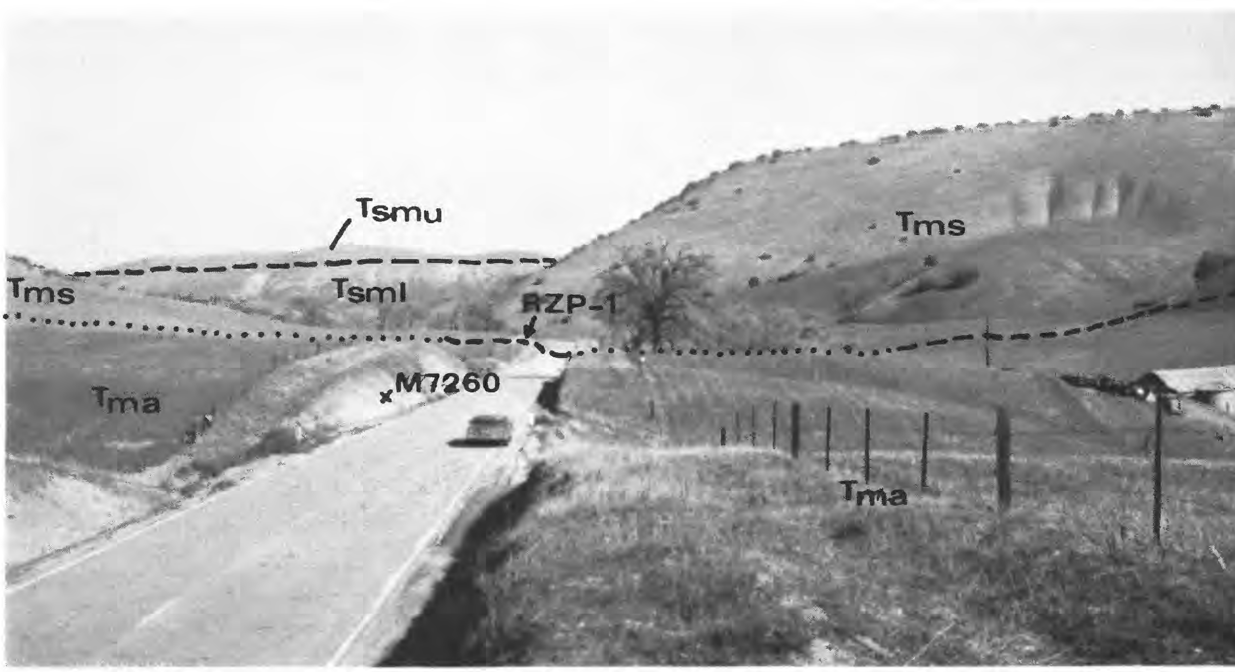

Figure 7. View looking northward along State Route 58 at Highland Ranch. Cuts in foreground expose fine- to very fine grained sandstone of the Saltos Shale Member of the Monterey Formation (Tma). The hillside on the right is formed of Sandholdt Member of the Monterey Formation (Tms), and the distant ridge is formed of Santa Margarita Formation; the top of the white unit marks the contact between the lower part (Tsml) and the upper part (Tsmu) of the formation.

located on the west side of the highway about 1.5 m above highway level in an area of very poor exposures. Exposures of the Sandholdt continue for about 1 km northward to Wilson Corner. Several microfossil localities are located along the east side of the road. Excellent exposures of the uppermost 40 m of the Sandholdt Member occur along the west bank of Indian Creek due west of Wilson Corner (fig. 8). The porcelaneous shale and phosphorite beds of the lower part of the Hames Member are exposed in a cut on the north side of the road intersection at Wilson Corner (fig. 9). The pelletal phosphorite beds reach as much as 6 cm in thickness (Dickert, 1966). Extensive trenching of this member along Indian Creek northwest of Wilson Corner during the 1960's was part of an evaluation of the commercial potential of these phosphate deposits but mining operations have never been attempted.

STOP 2. LUNCH IN THE OAKS ON SHELL CREEK.

The massive, macrofossil-rich sandstones at the base of the upper part of the Santa Margarita Formation are prominently exposed in the steep hillside about a kilometer northwest of here.

Figure 8. Uppermost 40 m of the Sandholdt Member of the Monterey Formation exposed on the west side of Indian Creek about 300 m west of Wilson Corner. View looking northwest. Luisian microfossil localities (RZP-3 and RZP-4) are about 1 m above stream level.

Figure 9. Porcelanite and 12-cm bed of pelletal phosphorite, indicated by pencil, exposed in cut on north side of State Route 58 at Wilson Corner (N1/2 of sec. 29, T. 28 S., R. 15 E.).

STOP 3. UPPER PART OF THE SANTA MARGARITA FORMATION.

The west and north slopes of a natural amphitheater on the west side of the Shell Creek road in the center of section 23 expose massive, mollusk-rich sandstone beds of the upper part of the Santa Margarita Formation (fig. 10). These coquinas are overlain by soft, medium- to coarse-grained sandstone containing locally dense accumulations of the echinoid *Astrodapsis* (fig. 11). This unit is especially fossiliferous near the top of the formation along Quailwater Creek about 8 km to the west (USGS locs. M2871 and M3735). Silty white sandstone at the top of the Santa Margarita Formation along the Shell Creek road contains abundant molds and casts of late Miocene mollusks including very abundant *Bulla cantuaensis* Anderson and Martin and *Protothaca staleyi* (Gabb). These highest Santa Margarita assemblages (USGS loc. M2859) are referable to the "Margaritan" Stage. This shallow-water stratum is unconformably overlain by brown-weathering gravels of the Paso Robles Formation (fig. 12).

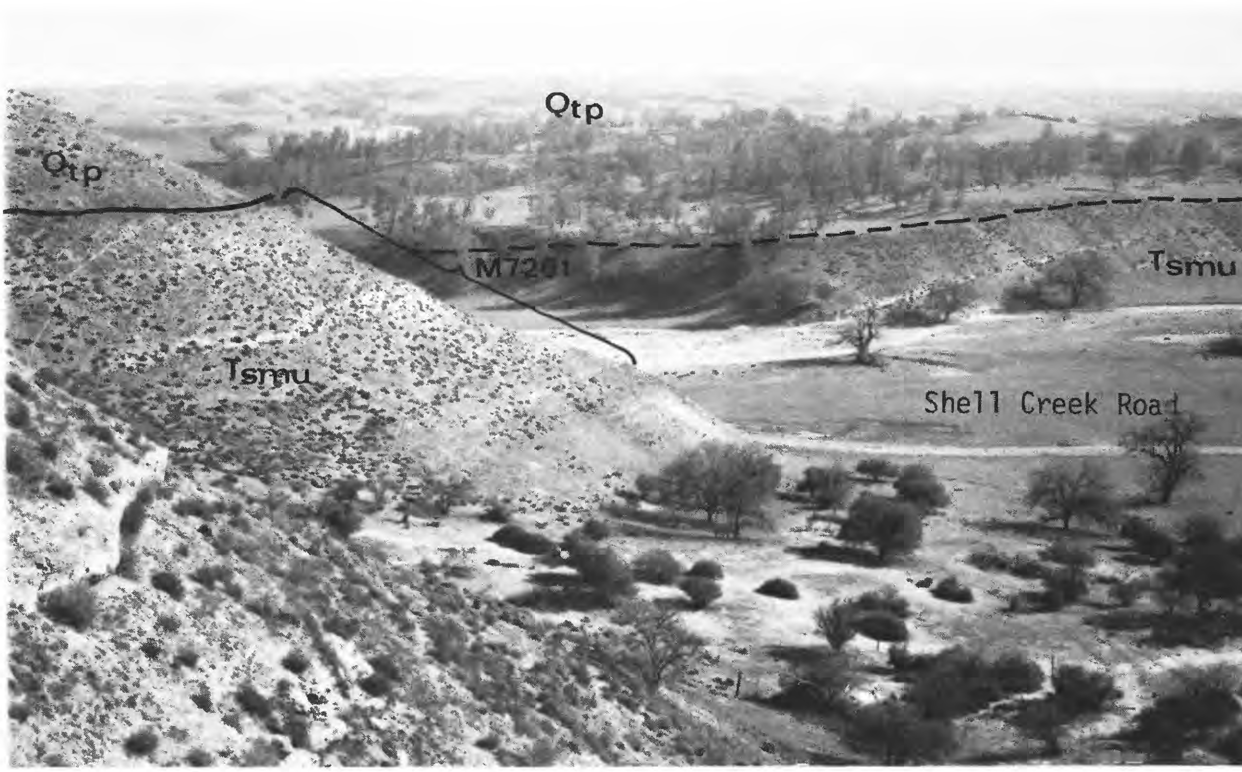

Figure 10. Massive, white sandstone of the upper part of the Santa Margarita Formation (Tsmu) on the west side of Shell Creek. Lyropecten- and Crassostrea-bearing biostromes exposed in the left foreground and on the east bank of Shell Creek. USGS loc. M7261 is a float collection from the upper 50 m of the Santa Margarita Formation, directly below the nonmarine Paso Robles Formation (QTp).

Figure 11. White coarse-grained sandstone in the upper part of the Santa Margarita Formation exposed along the west side of Shell Creek near the center of sec. 23, T. 28 S., R. 15 E. The contact between the Santa Margarita (Tsm) and the overlying Paso Robles Formation (QTpr) is indicated by the color change from white to gray at the bend in the road. The massive sandstone of the Santa Margarita contains the biscuit-like echinoid <u>Astrodapsis tumidus</u> Remond and the scallop <u>Lyropecten estrellanus</u> (Conrad).

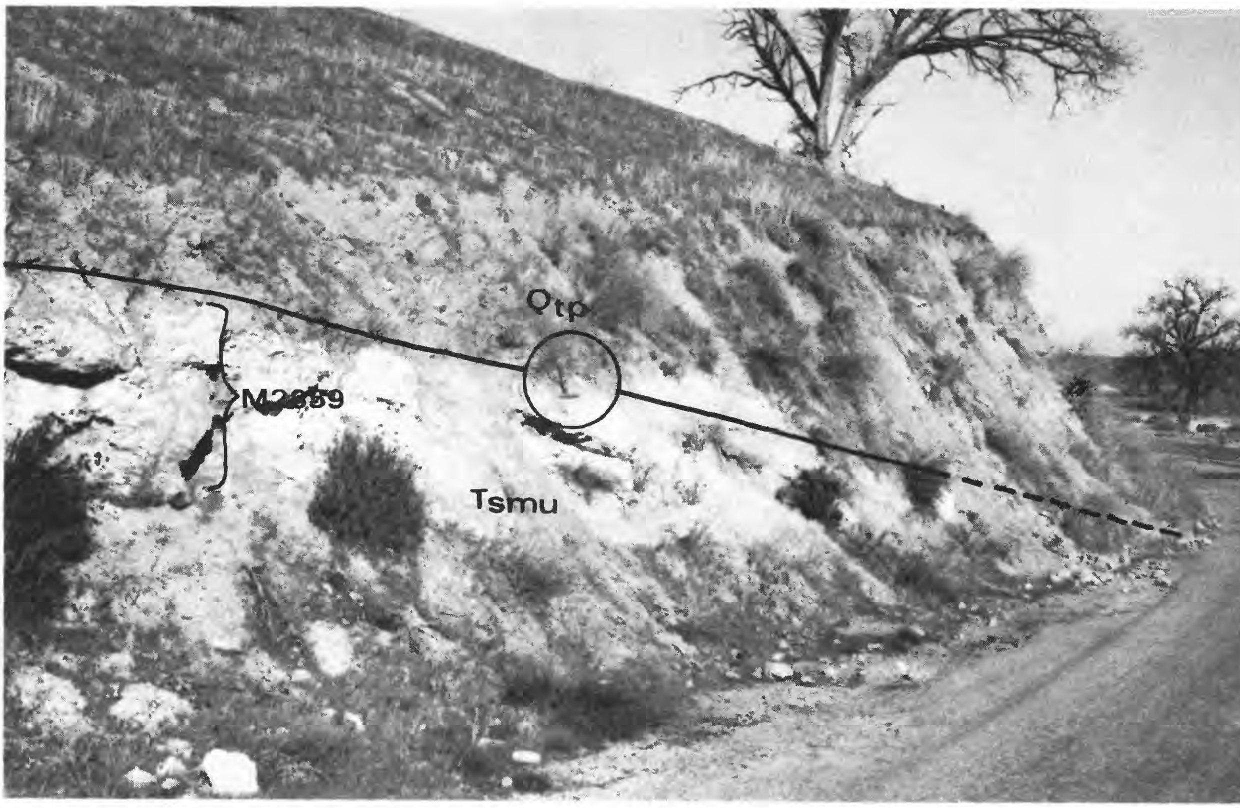

Figure 12. Unconformable contact between the Santa Margarita Formation (Tsmu) and the nonmarine Paso Robles Formation (QTp). Locality M2859 at the top of the Santa Margarita consists of a coquina of molds of *Protothaca staleyi* (Gabb), *Bulla cantuaensis* Anderson and Martin, and *Astraea biangulata* (Gabb).

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U.S. DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY

Patinopecten lohri (Hertlein), a late Miocene to Pliocene species from the Pancho Rico Formation (UCMP 36467, loc. A3161).

MARINE PALEOGEOGRAPHY AND PALEONTOLOGY OF THE SALINAS BASIN DURING THE LATEST PART OF THE MIOCENE WITH NOTES ON MACROFOSSILS FROM NEAR SAN LUCAS, CALIFORNIA

By Warren O. Addicott

INTRODUCTION

The Pancho Rico Formation is a relatively thin--up to 380 m (Durham, 1973)--sandstone and sandy mudstone unit of latest Miocene age in the Salinas basin of the central California Coast Ranges. The sandy facies are characterized by locally abundant macrofossils referable to the "Jacalitos" Stage of the California larger invertebrate chronology. This neritic unit represents the final regressive stage of the Miocene depositional cycle of the California Coast Ranges west of the San Andreas fault and the termination of marine conditions in the Salinas basin.

Outcrops of the Pancho Rico extend from the San Andreas fault westward to the foothills of the Santa Lucia Range, a distance of some 45 km. The formation extends some 80 km from San Benito southward to near San Miguel (fig. 1). Exposures along the east side of the basin define a broad, continuous outcrop pattern of gentle westward-dipping strata but along the west side exposures are confined to narrow belts and are discontinuous.

STRATIGRAPHY

The Pancho Rico Formation consists mostly of sandstone but there is also mudstone (sandy, diatomaceous and siliceous) and minor conglomerate. The formation unconformably overlies granitic basement of Late Cretaceous age in most of the northern part of the basin--the Gabilan High of Durham (1973). Farther south it overlies the Monterey Formation and, by inference, the Santa Margarita Formation in the southernmost part of its distributional area. The contact with the underlying mudstone and shale of the Monterey Formation is usually conformable. The Pancho Rico is conformably overlain by conglomerate and sandstone of the Pliocene and Pleistocene Paso Robles Formation in the northern part of its oucrop area. Farther south, the Paso Robles unconformably overlies the Pancho Rico (Durham, 1973); along the north margin of the La Panza Range conglomerate of the Paso Robles Formation directly overlies the Santa Margarita Formation which is the sandy, basin-margin facies equivalent of the siliceous shale (Hames Member) and diatomites (Buttle Member) of the Monterey Formation (Durham, 1973).

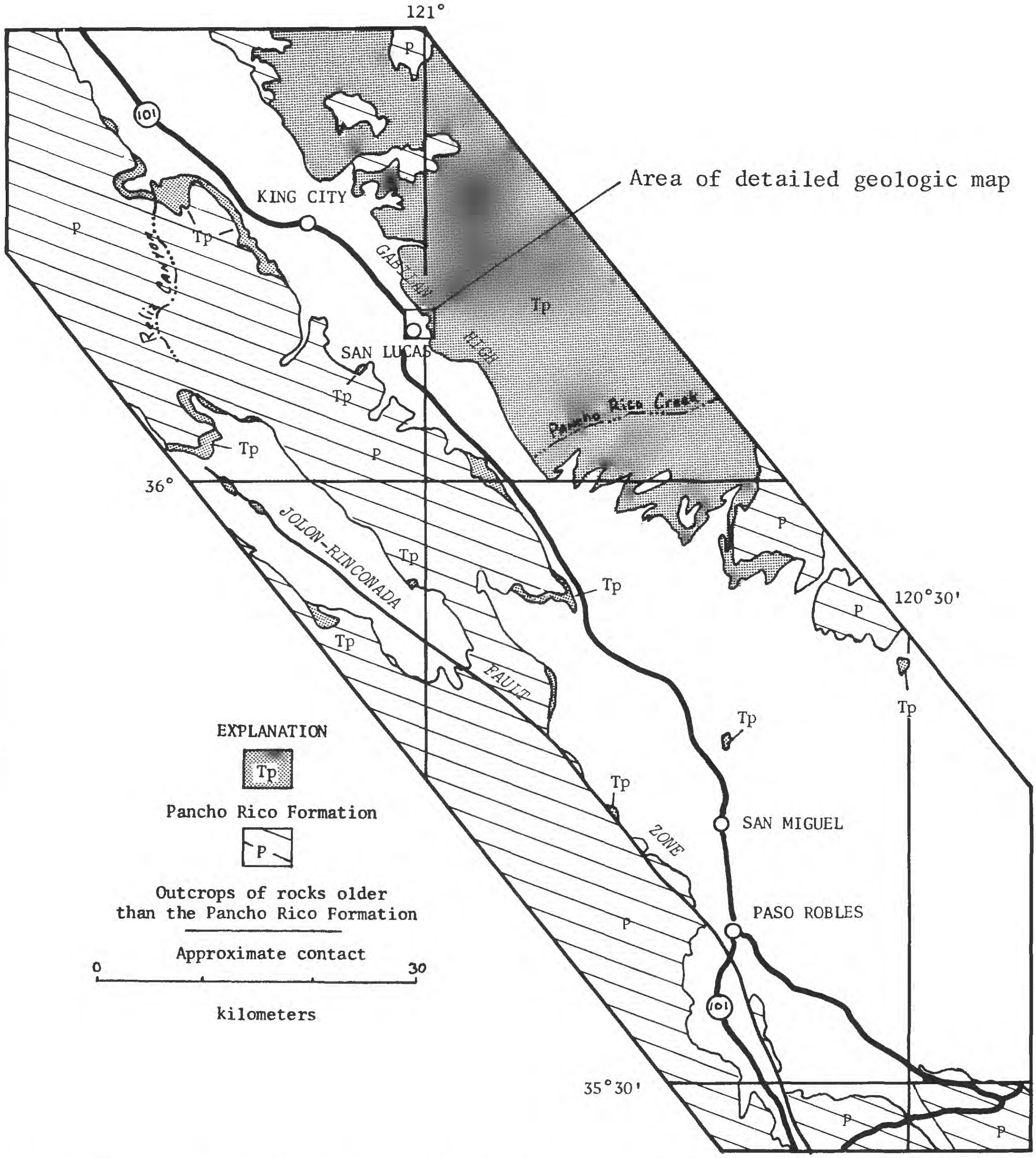

Figure 1. Map showing distribution of Pancho Rico Formation in the southern part of the Salinas basin and place names referred to in text (modified from Durham, 1973).

FOSSILS AND AGE

The invertebrate macrofauna of the Pancho Rico includes about 140 known taxa (Durham and Addicott, 1965) of which pectinids, muricid gastropods, sand dollar echinoids, and a giant barnacle are the most conspicuous elements. There is a very close correspondence with the fauna of the so-called Jacalitos Formation (lower part of the Etchegoin Formation) of the Coalinga area of the San Joaquin basin to the east. Accordingly, the Pancho Rico has been referred to the "Jacalitos" Stage and, until recently, has been considered early Pliocene (Nomland, 1917; Woodring and Bramlette, 1950; Durham and Addicott, 1965). Recalibration of the California provincial benthic chronologies (Berggren, 1969, 1972; Addicott, 1972, fig. 3), however, has shown that this part of the Neogene is of latest Miocene age in terms of the European standards. Foraminiferal assemblages from the Pancho Rico contain a few benthic species of shallow-water aspect that are not age diagnostic. The only diatom and silicoflagellate assemblage from the Pancho Rico--a locality about 16 km northeast of King City--contains a mixture of late Miocene and late Pliocene species (Wornardt, 1967).

PALEOECOLOGY AND PALEOGEOGRAPHY

Although detailed paleoenvironmental study of fossil associations in the Pancho Rico Formation has not been made, at least two macrofossil biofacies that are useful in basin analysis can be recognized. A shallow, warm-water barnacle-echinoid association occurs in the broad outcrop area in the central and eastern part of the basin (fig. 1). Many mollusks from localities in this area and the southwestern part of the basin are related to southern species that live in tropical and subtropical waters off the west coast of Central America. This warm, extremely shallow-water facies contrasts with deeper inner sublittoral assemblages from the Reliz Canyon area in the northwest part of the basin. The northern and cooler water affinities of these assemblages, together with the maximum recorded thicknesses of the Pancho Rico in this area (about 380 m), suggest a northward or northwestward connection with the open ocean during the latest part of the Miocene. A probable seaward connection from the southwestern part of the basin through the Santa Maria basin (fig. 2) is indicated by the apparent interchange of marine life between these two basins during the latest Miocene (Durham and Addicott, 1965; Addicott and Galehouse, 1973).

The paleogeography of the Salinas basin during the latest part of the Miocene has been utilized in defining post-late Miocene slip along two major faults in central California. Pancho Rico-like faunas occur in sandstones of the Panorama Hills Formation on the east side of the San Andreas fault (Addicott, 1972) and have been matched with the southernmost sandstones of the Pancho Rico Formation that lie on the opposite side of the fault but much farther to the northwest (Dibblee, 1966). The implied 80 km of post-late Miocene right-lateral slip along this part of the San Andreas is somewhat less than the 100 km of slip postulated by Galehouse (1967) from regional paleogeography and assumed rates of 10-13 km of slip per million years. Apparent right-lateral displacement of more than 18 km along the Jolon-Rinconada fault zone northwest of Paso Robles following deposition of the Pancho Rico

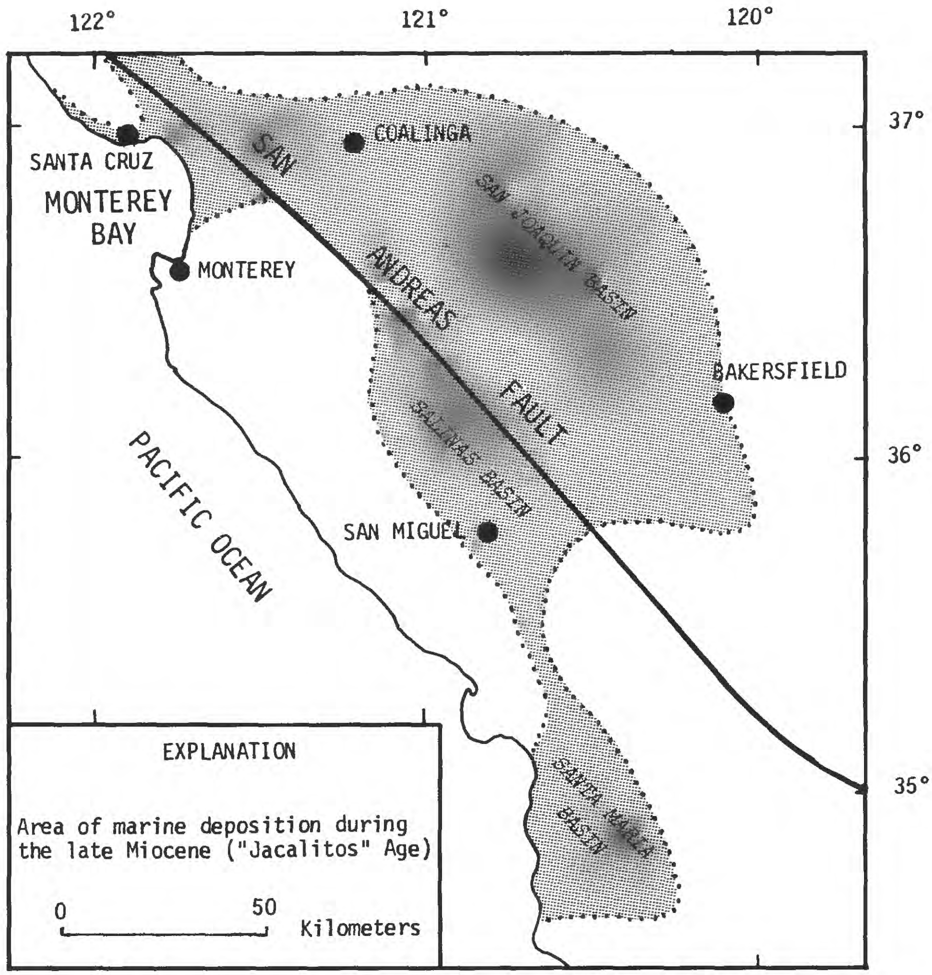

Figure 2. Latest Miocene paleogeography of central California prior to displacement along the San Andreas fault showing postulated marine seaway between the Salinas and Santa Maria basins (from Addicott and Galehouse, 1973).

Formation has been postulated by Durham (1965, 1973). This figure is based in part on the occurrence of Pancho Rico Formation outcrops farther to the south on the east side of the fault than on the west side (fig. 1).

MACROFOSSIL LOCALITY NEAR SAN LUCAS

Exposures on a small hillock about one kilometer northeast of San Lucas, Calif. (fig. 3), are fairly typical of the fossiliferous sandstones of this formation. The white, medium-grained sandstone contains a fauna of 29 larger marine invertebrates, principally mollusks. Massive, locally bioclastic sandstone forms unusually bold exposures about 20 m thick on the west side of State Route 198 (fig. 4). Preservation of calcitic-shelled macrofossils--principally pectinids, echinoids, and muricid gastropods--at this isolated but readily accessible locality (USGS M903), is unusually good. Aragonitic-shelled

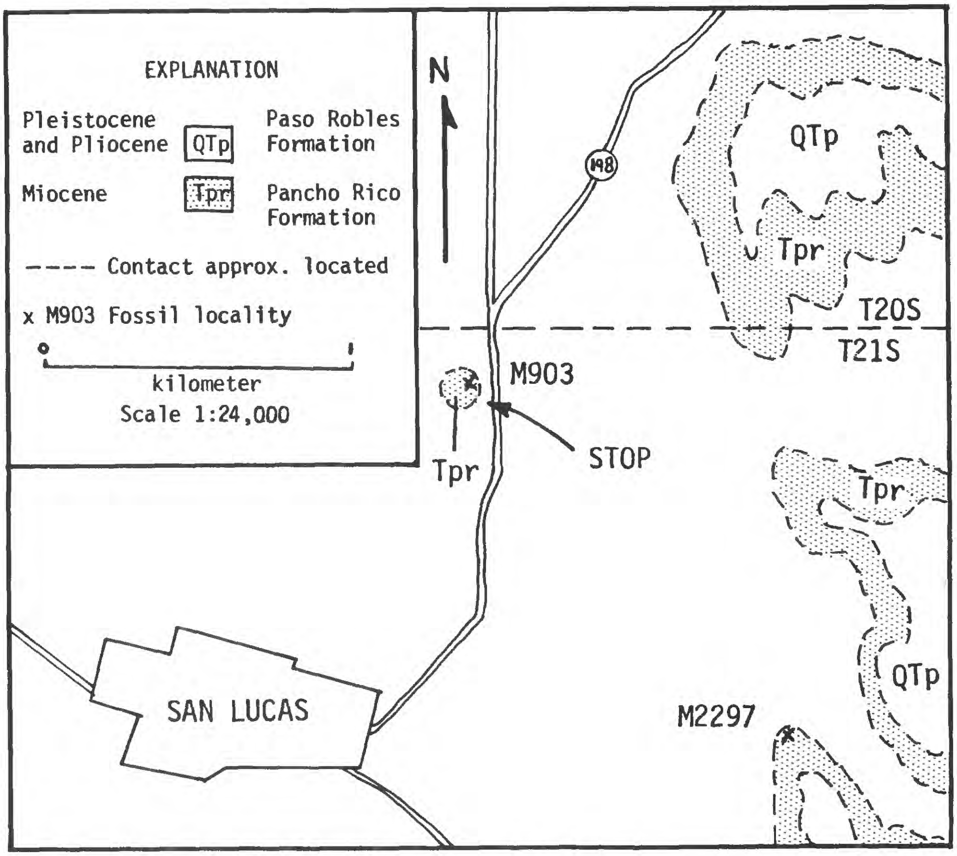

Figure 3. Map showing distribution of Pancho Rico and Paso Robles Formations northeast of San Lucas and fossil localities (mostly from Durham, 1963). Large unmarked area is underlain by semiconsolidated older alluvium of Pleistocene age.

Figure 4. Massive, locally bioclastic sandstone of Pancho Rico Formation 1 km northeast of San Lucas (USGS loc. M903). View looking west from State Route 198.

mollusks are abundant here, and at other localities in the Pancho Rico, but they are represented by external molds from which latex rubber casts have been made for study. This type of preservation is common for the Pancho Rico mollusk fauna; well-preserved aragonitic-shelled mollusks are uncommon.

The dominant species at this locality are a form of Lyropecten estrellanus (Conrad) with square ribs, an undescribed species of Acanthina and of Ocenebra, Astrodapsis spatiosus Kew, A. fernandoensis, and Balanus gregarius (Conrad). Clumps of this spectacular giant barnacle from nearby localities reach as much as 27 cm in height. These, and other species, are listed in Table 1. One of the most commonly occurring mollusks in the Pancho Rico Formation is Lyropecten terminus (Arnold)--a species with consistently fewer and broader radial ribs than the 16-18 ribbed specimens of L. estrellanus (Conrad) that occur at this locality. L. terminus is reported from a locality in the bluffs east of Salinas River about 4 km southeast of here and is extremely abundant in the Wildhorse Canyon area about 6 km to the north.

Foraminifer assemblages in the Pancho Rico Formation are of low diversity consisting of long-ranging species indicative of depths of less than 50 m according to P. B. Smith (written commun., 1960). The following benthic species were identified by Smith from a locality in Coyote Canyon about 7 km southeast of San Lucas: Elphidiella hannai, Elphidium hughesi, E. poeyanum, Buccella frigida, and Trochammina sp.

Table 1. Macroinvertebrate fossils from USGS loc. M903 near San Lucas (Pancho Rico Formation, late late Miocene).

Echinoids:
- Astrodapsis fernandoensis Pack
- Astrodapsis spatiosus Kew
- Dendraster sp.

Gastropods:
- Acanthina n. sp.
- Calliostoma coalingense Arnold
- Calyptraea sp.
- Ceratostoma foliatum (Gmelin)
- Ceratostoma nuttalli (Conrad)?
- Epitonium cf. E. eelense Durham
- Forreria belcheri (Hinds)?
- Forreria cf. F. coalingensis (Arnold)
- Megasurcula n. sp. aff. M. wynoocheensis (Weaver)
- Nucella collomi (Carson)
- Ocenebra cierboensis (Grant and Eaton)
- Ocenebra n. sp.
- Turritella cooperi Carpenter

Bivalves:
- Anomia? sp.
- Atrina sp.

Chione cf. C. fernandoensis English
Chlamys sp.
Crenomytilus cf. C. kewi (Nomland)
Clinocardium sp.
Glycymeris sp.
Lima cf. L. hemphilli Hertlein and Strong
Lyropecten estrellanus (Conrad) 16-18 ribbed form
Miltha sp.
Panopea abrupta (Conrad)
Tellina cf. T. idae Dall

Barnacle:
Balanus gregarius (Conrad)

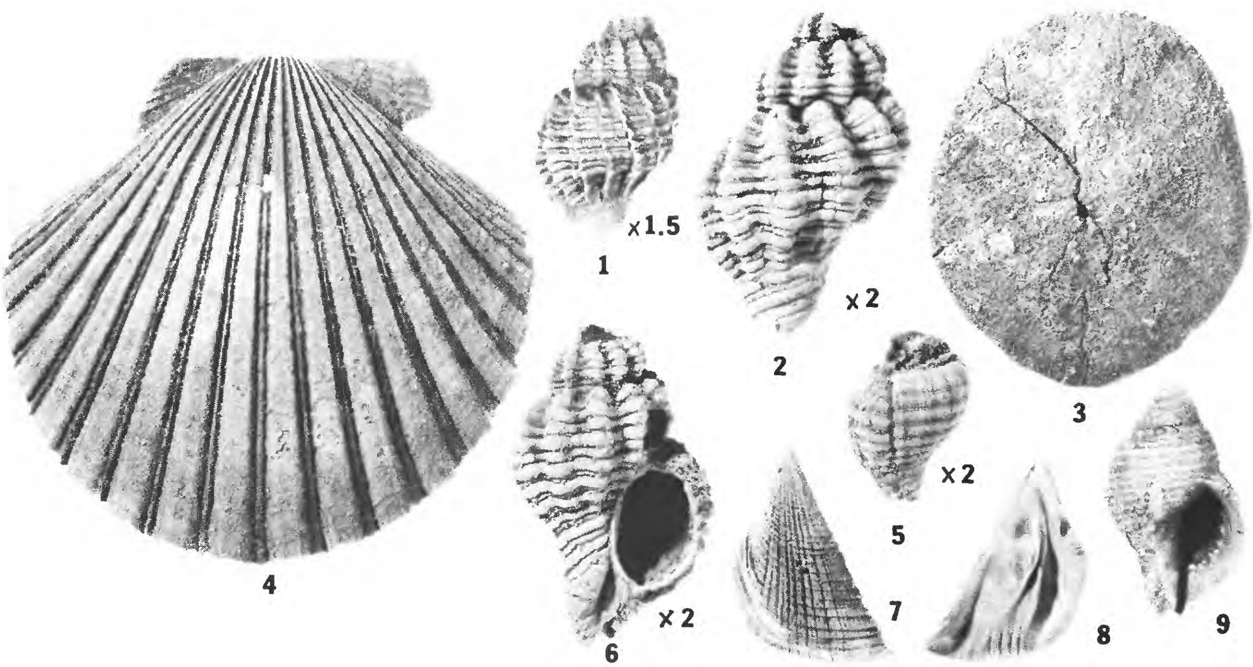

Plate 1

Mollusks and echinoid from USGS loc. M903, Pancho Rico Formation, near San Lucas, California. Specimens natural size unless otherwise indicated.

Figures 1. Ocenebra cierboensis (Grant and Eaton). USNM 254346.
2, 6. Ocenebra n. sp. Durham and Addicott. USNM 254347.
3. Astrodapsis spatiosus Kew. USNM 254348.
4. Lyropecten estrellanus (Conrad) 16-18 ribbed form. USNM 254349.
5. Acanthina n. sp. Durham and Addicott. USNM 254350.
7, 8. Balanus gregarius (Conrad). USNM 649172.
9. Nucella collomi (Carson). USNM 254388.

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NOTES ON THE GEOLOGY OF POINT LOBOS STATE RESERVE, MONTEREY COUNTY, CALIFORNIA

by Warren O. Addicott

Point Lobos State Reserve is a rugged northwest-trending headland composed of granodiorite of Late Cretaceous age and submarine fan deposits of Paleocene age. The picturesque cliffs and offshore rocks, pocket beaches, and gnarled cypress and pine trees of this promontory form one of the most scenic and photographed parts of the California coast. Point Lobos lies a few kilometers south of the Monterey Peninsula and bounds Carmel Bay on the southwest (fig. 1). The Spanish word, Lobos, is for the noisy colonies of California and Steller sea lions that inhabit the offshore rocks. The sedimentary geology of Point Lobos has been studied in detail by Nili-Esfahani (1965). A popular account of the geology of Point Lobos was written by Bowen and others (1965).

Conglomerate, sandstone, and laminated siltstone of the Carmelo Formation of Bowen (1965) are exposed in the seacliffs, small headlands, and offshore rocks at Point Lobos. Other exposures of this formation occur on the north side of Carmel Bay, about 5 km to the north (fig. 1), where the sequence is less complicated structurally (Clark and others, 1974) and somewhat thicker. At Point Lobos these marine strata reach a maximum thickness of 200 m on the southwest coast between Hidden Beach and Pebbly Beach. They occur in a complexly folded and faulted sequence that lies in fault contact with granodiorite of Late Cretaceous age at Hidden Beach near China Cove (Clark and others, 1974). On the west and northwest shores of Point Lobos conglomerate and sandstone of the Carmelo Formation unconformabliy overlie Late Cretaceous granodiorite.

The basal part of the Carmelo Formation consists of graded pebble and cobble conglomerate with clasts of porphyritic andesite, rhyolite and granitic rock. This part of the Carmelo is best exposed on the west shore at Sea Lion Point (Punta de los Lobos Marinos); the unconformable contact with Mesozoic granodiorite is well exposed northeast of the point in the seacliff on the north side of Headland Cove. Scattered interbeds of shale occur in the basal part of the formation; one of these near China Cove on the southwest coast yielded an arenaceous foraminifer assemblage of 16 species of Paleocene age (Bowen and others, 1965). At Gibson Beach near the southern boundary of the State Reserve the distinctive Paleocene gastropod Turritella pachecoensis has been collected from the upper part of the formation (Bowen, 1965; Nili-Esfahani, 1965).

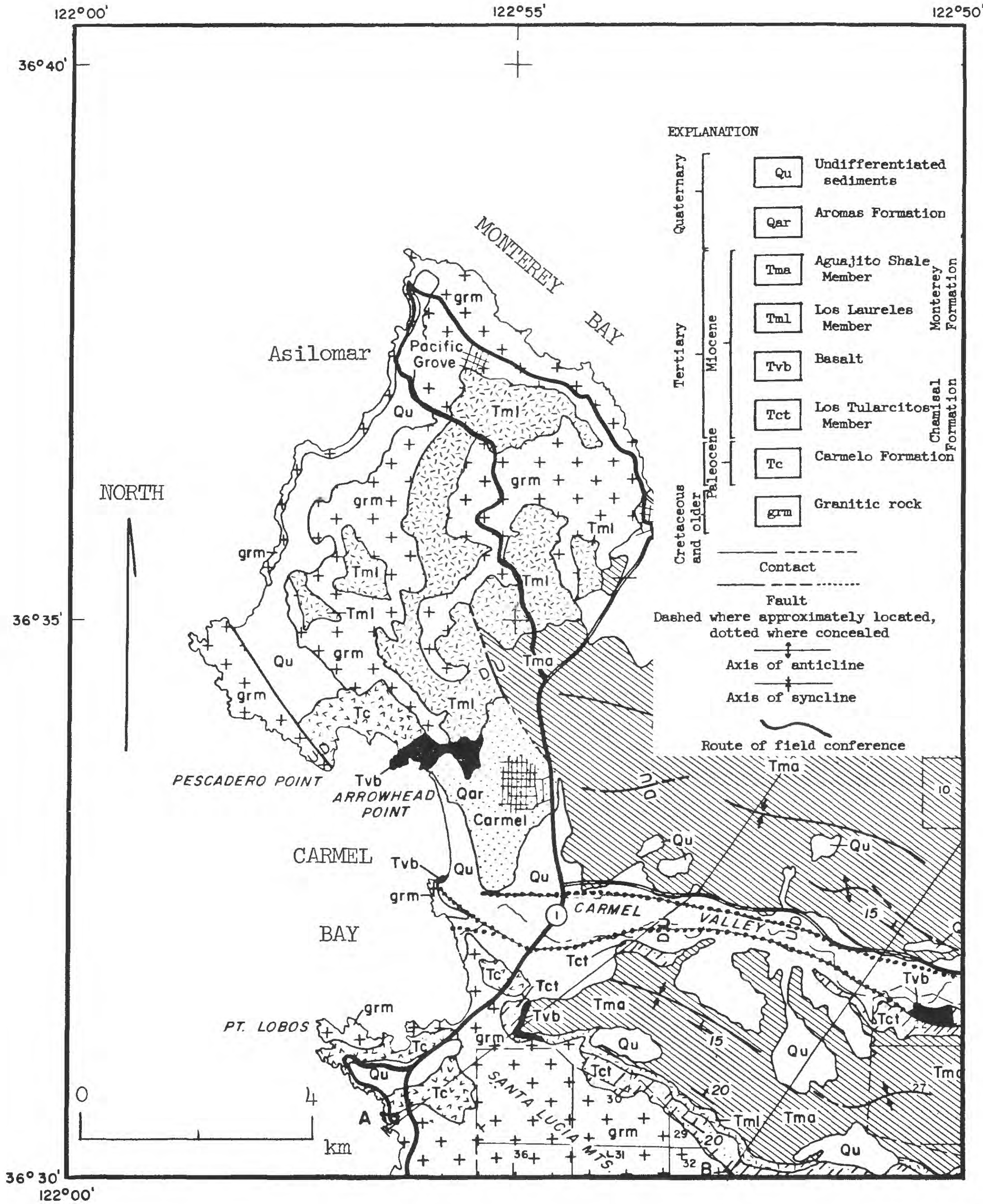

Figure 1. Geologic index map of Monterey Peninsula-Point Lobos area showing generalized distribution of rock units (from Bowen and others, 1965).

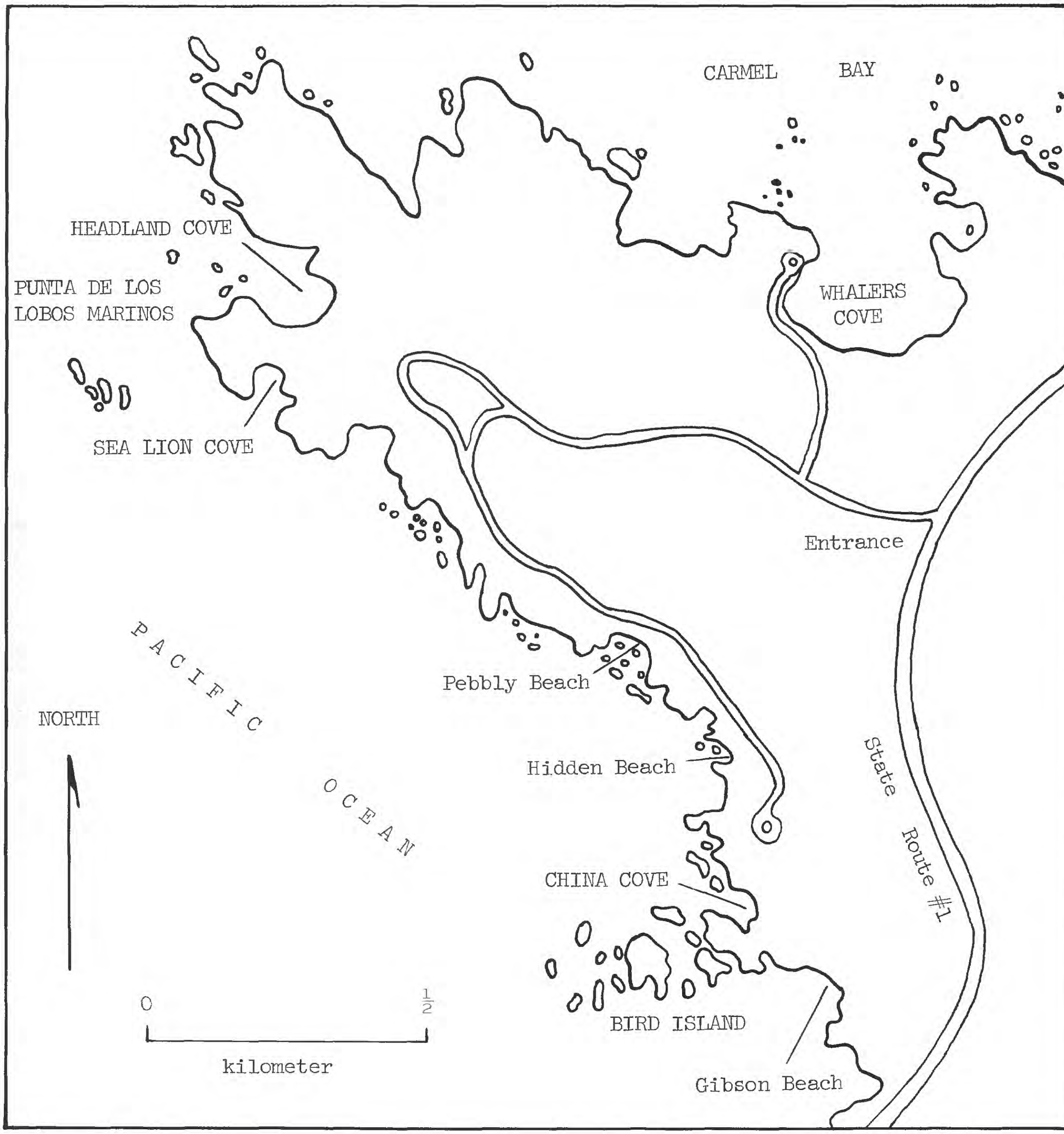

Figure 2. Index map of Point Lobos State Reserve showing place names referred to in text.

Scattered mollusks and foraminifers of Paleocene age are also known from exposures on the north side of Carmel Bay (Bowen and others, 1965).

Three units have been recognized and mapped within the Carmelo Formation on the south coast at Point Lobos (Nili-Esfahani, 1965). The lowest is conglomerate with sandstone and scattered shale interbeds. Shale is relatively common in this unit only on the north shore of Point Lobos. Paleocene microfossils have been found near the base of this unit. The intermediate unit is composed of sequences of conglomerate, sandstone, and laminated siltstone that occur in regular (coarse grading upward to fine-grained) or inverted (fine grading to upward coarse-grained) sequences. The highest unit consists of siltstone, shale, and sandstone that are best exposed in synclines on the southwest shore of Point Lobos. The middle and upper units are well exposed at Pebbly Beach on the southwest coast.

Bedding features in the Carmelo Formation include slump structures, flame structures, flute casts, groove casts, load casts, graded bedding, and convolute

Figure 3. Sandstone with ripple-marked surfaces in the middle part of the Carmelo Formation at Pebbly Beach. View looking northwest.

bedding (Bowen, 1965; Nili-Esfahani, 1965), suggesting deposition by gravity sliding, submarine slumping, and turbidity currents. Trace fossils and ripple marks occur at the top of beds in the finer grained strata in the middle and upper parts of the Carmelo Formation, excellent examples occur at Pebbly Beach. Supposed algal fossils (Class Rhodophyceae) reported by Nili-Esfahani (1965) have subsequently been reinterpreted as feeding traces of benthic invertebrates that are considered to be undescribed trace fossils (Gary Hill, personal commun., 1978). Paleocurrent determinations suggest that the lower and middle parts of the section were deposited by currents generally flowing north to north-northwest but that the fine clastic sediments of the upper part were derived from a north to north-northeast direction (Nili-Esfahani, 1965).

Sedimentary features and the scant fossil data suggest that the Carmelo Formation was deposited in an upper slope or bathyal environment as part of a submarine fan system (Gary Hill, personal commun., 1978).

Figure 4. Bird Island and offshore rocks composed of Late Cretaceous granodiorite. View looking west from China Cove.

Figure 5. Conglomerate with interbeds of coarse-grained sandstone near the base of the Carmelo Formation. View looking northwest from cliff on south side of Hidden Beach.

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MARINE LATE NEOGENE SEQUENCE NEAR SANTA CRUZ, CALIFORNIA

By Warren O. Addicott, John A. Barron, and John W. Miller

INTRODUCTION

A late Neogene sequence of neritic mudstone and sandstone containing locally abundant siliceous microfossils and megafossils is exposed in seacliffs that border the southern part of the Santa Cruz Mountains from Rio del Mar northwestward 40 km to Point Ano Nuevo. Marine Miocene formations dip gently seaward along its southwest and southern margins. This sequence defines a marine cycle of deposition that began during the late Miocene (Mohnian and "Margaritan" Stages). It is deposited on the granitic and metasedimentary core of Ben Lomond Mountain, a northwest-trending basement high in the southwest part of the Santa Cruz Mountains, and dips gently seaward from the southwestern and southern margins of this basement high.

The early part of the late Miocene is represented by a basal sandstone of variable thickness, the Santa Margarita Formation. It unconformably overlies granitic rock north of Santa Cruz where it reaches a maximum thickness of about 130 m. The Santa Margarita contains locally rich accumulations of the sand dollar echinoid *Astrodapsis* in addition to shark teeth, 6 species of land mammals, and possibly 10 species of marine mammals and birds.

The conformably overlying organic Santa Cruz Mudstone of Clark (1966) crops out continuously along the coast from Santa Cruz almost to Point Ano Nuevo, about 30 km to the northwest. This siliceous unit varies in thickness from about 140 m at the type locality in Santa Cruz to almost 3,000 m in a bore hole located about 25 km to the northwest (Clark, 1966).

The youngest Neogene unit is the latest Miocene and Pliocene Purisima Formation which unconformably overlies the Santa Cruz Mudstone in the southwest part of Santa Cruz. The formation crops out almost continuously from Santa Cruz eastward to Rio del Mar, a distance of about 11 km. A somewhat thicker but lithologically similar section of the Purisima Formation is exposed in seacliffs immediately east of Point Ano Nuevo. The Purisima Formation grades upward from diatomaceous mudstone through fine- to very fine grained sandstone to coarse-grained and locally conglomeratic fossiliferous sandstone in the upper part. A thin basal conglomeratic and glauconitic sandstone marks the unconformable contact with the older Miocene units. The Purisima Formation is mostly Pliocene in age, although diatoms and a radiometric age determination from the lowest part of the formation indicate a late late Miocene age.

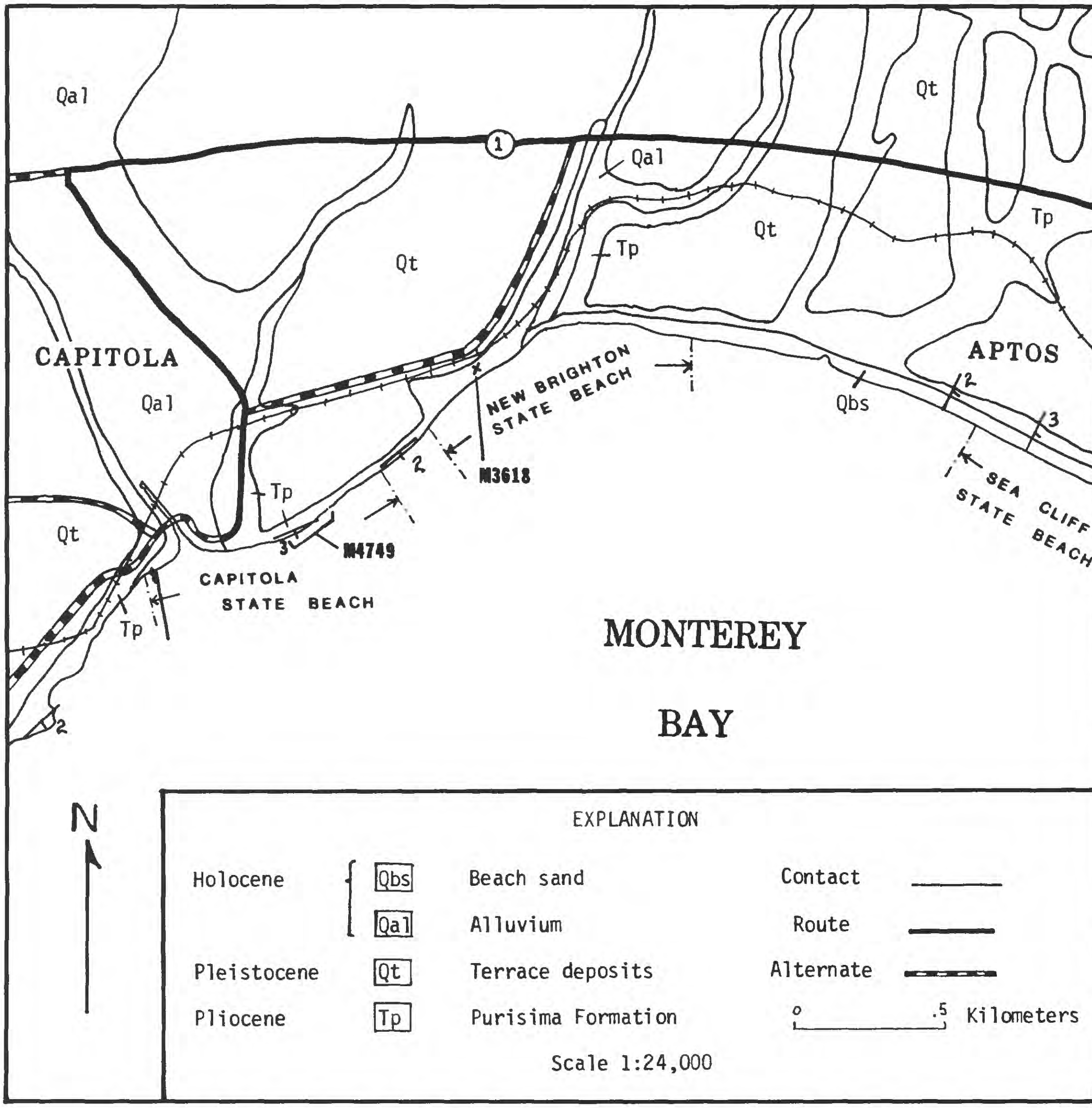


Figure 1. Geologic map of the Capitola, New Brighton, and Seacliff State Beaches area near Santa Cruz, California, showing some fossil localities in the Purisima Formation.

UPPER PART OF THE PURISIMA FORMATION AT CAPITOLA STATE BEACH (STOP 1)

The uppermost 50 to 100 m of the Purisima Formation exposed in the seacliffs from Capitola State Beach (fig. 1) eastward for about 4 km to Rio del Mar consists of medium- to coarse-grained concretionary sandstone with occasional shell beds. Excellent exposures at Capitola State Beach (loc. M4749) and New Brighton State Beach (loc. M3618) yield a fauna of 26 mollusks of Pliocene age (table 1). Species restricted to the Pliocene (about 5 to 1.8 my) include Beringius stantoni, Ophiodermella graciosana, and Macoma addicotti.

Table 1. Mollusks from the Purisima Formation near Santa Cruz, California.

Species	Localities: Capitola State Beach USGS M4749	Localities: New Brighton State Park USGS M3618
BIVALVES:		
Anadara trilineata (Conrad)	x	x
Clinocardium meekianum (Gabb)	x	-
Cryptomya californica (Conrad)	x	-
Macoma addicotti Nikas	x	x
Macoma nasuta (Conrad)	x	x
Modiolus sp.	x	-
Lucinoma annulata (Reeve)	x	-
Protothaca staleyi (Gabb)	x	-
Siliqua sp.	x	-
Solen sicarius Gould	x	x
Spisula albaria (Conrad)	x	-
Spisula sp.	x	-
Tresus pajaroanus (Conrad)	x	x
Yoldia (*Kalayoldia*) sp.	x	-
GASTROPODS:		
Beringius stantoni (Arnold)	-	x
Cryptonatica clausa (Broderip and Sowerby)	-	x
Calicantharus portolaensis (Arnold)	x	-
Calyptraea inornata (Gabb)	x	-
Crepidula princeps Conrad	x	x
Mitrella gouldi (Carpenter)	x	x
Megasurcula sp.	x	-
Nassarius grammatus (Dall)	x	x
Neverita recluziana (Deshayes)	x	-
Olivella biplicata (Sowerby)	x	-
Ophiodermella graciosana (Arnold)	x	x
Polinices lewisii (Gould)	x	x

The seacliff at Capitola State Beach (fig. 2) exposes almost 15 m of massive medium to coarse-grained gray sandstone that is unconformably overlain by 4 to 5 m of late Pleistocene terrace deposits. The middle 5 m of the Purisima at this locality is characterized by concretions that average about 0.33 m in diameter. Otarioid seal remains are reported from these exposures by Repenning and Tedford (1977).

The locality at New Brighton State Beach, about 1 km to the northeast, is slightly higher stratigraphically (fig. 1) but contains an almost identical, but somewhat smaller, molluscan assemblage (table 1). Scattered sand dollar echinoids, barnacles, and whale bones also occur at this locality which is

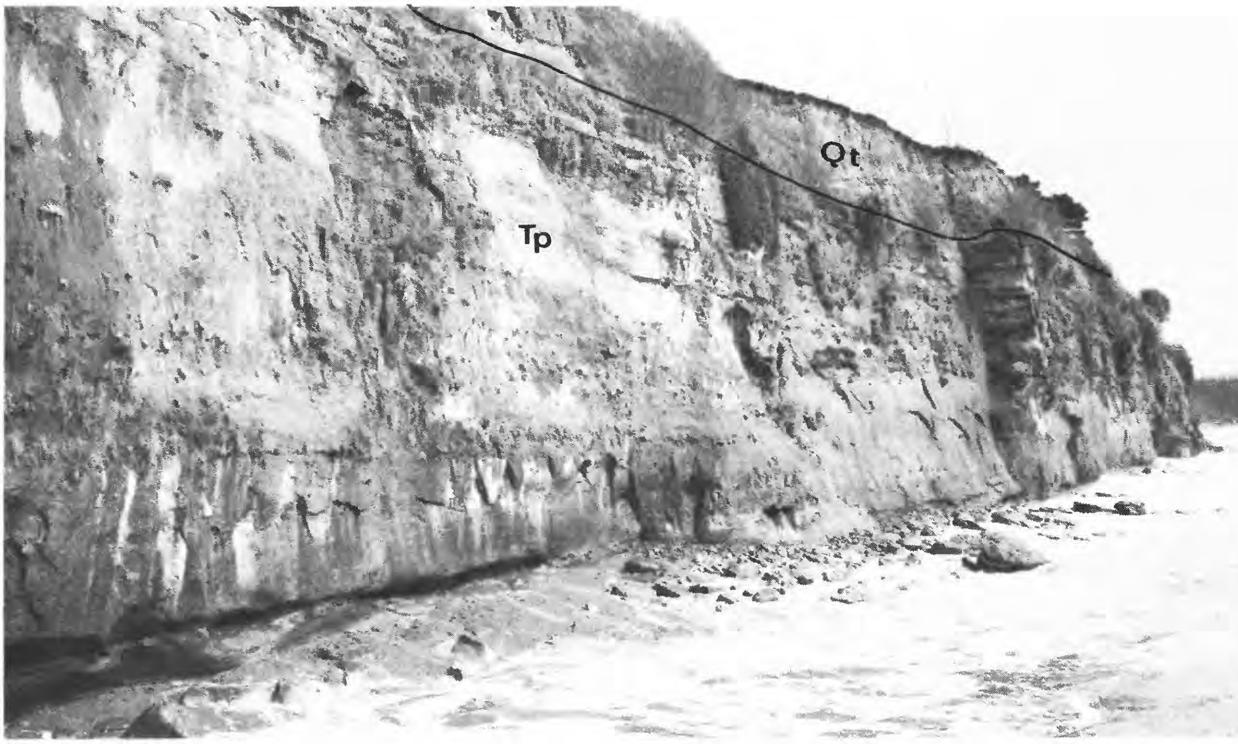


Figure 2. Purisima Formation (Tp) unconformably overlain by late Pleistocene terrace (Qt) at Capitola State Beach. View looking north-northeast.

accessible at high tide whereas the Capitola locality must be visited at low tide. Fossil collecting from the seacliffs is prohibited by law on these state-owned beaches, nevertheless good material generally can be observed in slump blocks and water-worn fossiliferous boulders in the intertidal zone. Fossils noted from localities M4749 and M3618 were collected from slump blocks.

Mollusks are common in soft, poorly consolidated sandstone exposed in the low seacliffs that extend from New Brighton State Beach southeastward to Seacliff State Beach. The Purisima is conformably overlain by nonmarine sand of the Pliocene and Pleistocene Aromas Formation; the contact is placed at the highest occurrence of marine fossils near the pier at Seacliff State Beach (E. E. Brabb, oral commun., 1978).

The mollusk assemblage of the upper part of the Purisima Formation of the Capitola area is almost identical to that of the sandstones in the upper part of the formation exposed east of Point Ano Nuevo (USGS loc. M2146), about 40 km to the northwest (Brabb and others, 1977). The distinctiveness of these assemblages led Arnold (in Branner and others, 1909) to differentiate these sandstones from the underlying part of the Purisima Formation in these two areas and to assign them to the Merced Formation. The faunas are very similar to those of the Merced Formation (Addicott, 1969) but it has been the practice, in recent years, to limit recognition of the Merced Formation to areas northeast of the San Andreas fault.

PURISIMA FORMATION AT POINT SANTA CRUZ (STOP 2)

Fine- to very fine grained concretionary sandstone of the Purisima Formation is exposed in steep cliffs at Point Santa Cruz, a prominent headland lying at the southwest edge of Santa Cruz Harbor (fig. 3). The point (fig. 4) is a gathering place for surfing enthusiasts and it is also an excellent place for viewing Steller and California sea lions that frequent Seal Rock, located about 50 m offshore. Exposure of the Purisima near Santa Cruz Point have yielded several significant specimens of otarioid seals (Mitchell, 1962; Repenning and Tedford, 1977) and whales (Barnes, 1976) (figure 3). An illustrated popular

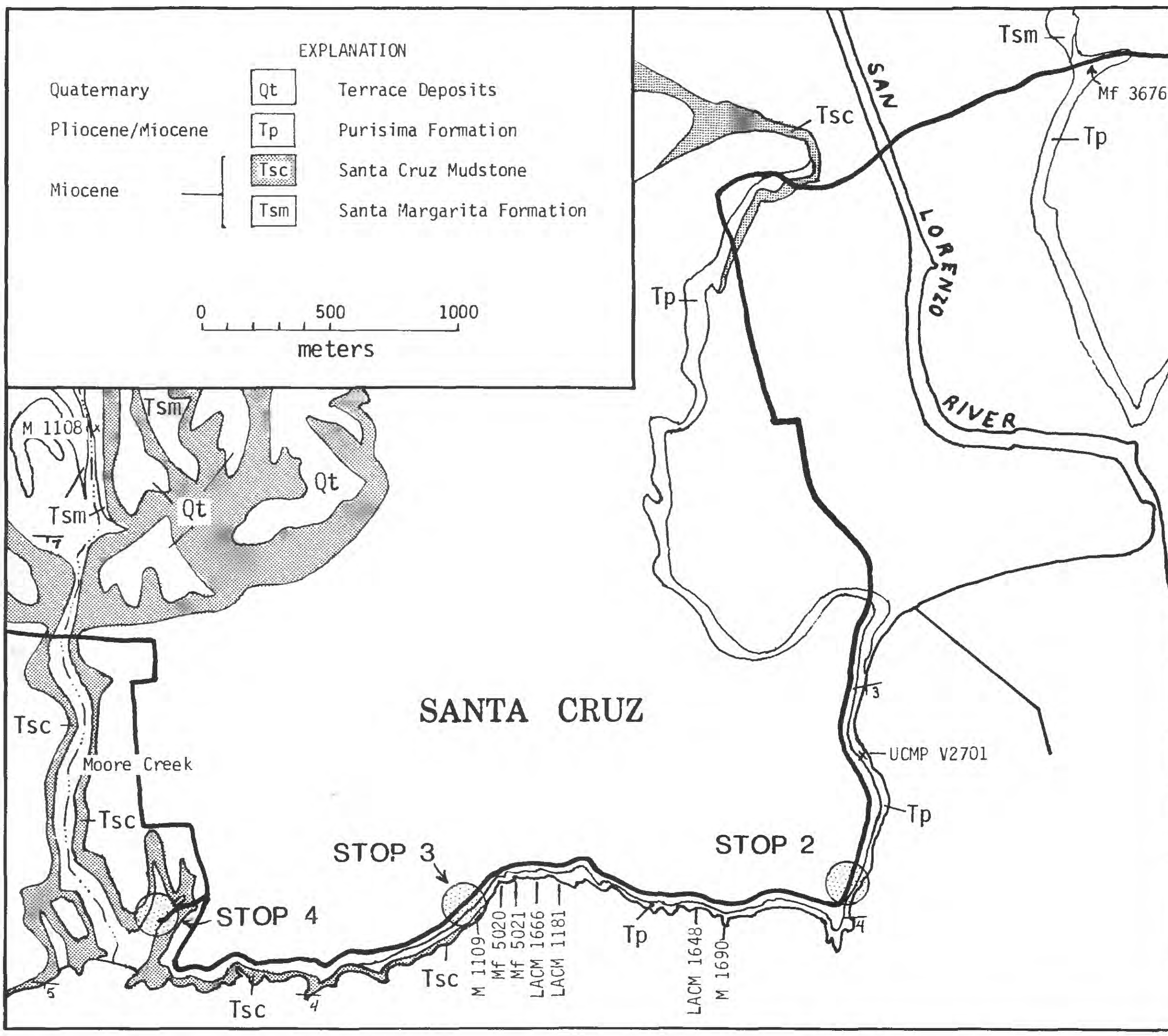


Figure 3. Generalized geologic map of the Santa Cruz area showing fossil localities (compiled from Clark, 1966). USGS Mf5020 and Mf5021 are Neogene microfossil localities; LACM 1181, 1648, and 1666, and UCMP V2701 are Neogene marine vertebrate localities; USGS M1690 is a late Pleistocene marine invertebrate locality and USGS M1108 and 1109 are late Miocene marine vertebrate localities.

Figure 4. Purisima Formation on the west side of Point Santa Cruz (west of stop 2). View looking southeast.

account of the late Neogene fossils of this area (Perry, 1977) has been published by the Santa Cruz City Museum, 1305 East Cliff Drive, Santa Cruz, Calif. 95062. Marine terrace deposits that unconformably overlie the Purisima Formation on a small promontory at the west edge of the beach about 400 m west of the lighthouse at Point Santa Cruz (USGS loc. M1690, fig. 3) have yielded an assemblage of 60 larger marine invertebrates and 16 foraminifers of late Pleistocene age (Addicott, 1966). This terrace can be traced northwestward to Point Ano Nuevo (Bradley and Griggs, 1976) where similar invertebrate faunas of cool-water aspect have been found.

SANTA CRUZ MUDSTONE/PURISIMA FORMATION CONTACT AT SANTA CRUZ (STOP 3)

The contact between the Santa Cruz Mudstone of Clark (1966) and the overlying Purisima Formation is clearly exposed in the seacliff along West Cliff Drive about 1 km west of Point Santa Cruz. Concrete stairs next to a large cypress tree provide convenient access to the beach just west of the intersection of West Cliff Drive and de la Costa Street. At the base of the stairs a broad wave-cut platform marks the top of the massive, siliceous mudstone of the Santa Cruz Mudstone (fig. 5). The lowest part of the Purisima Formation consists of a conglomeratic sandstone, about 1 m thick (fig. 6), that contains glauconite, pebbles and cobbles of siliceous mudstone, granitic and silicic metaporphyry rock, and scattered bones of pinnipeds, cetaceans, and sirenians as well as shark teeth (Clark, 1966).

Figure 5. Unconformable contact between the Santa Cruz Mudstone (Tsc) and the overlying Purisima Formation (Tp) in seacliffs near West Cliff Drive and de la Costa Street, southwest Santa Cruz (stop 3). View looking east.

The sandstone grades upward into punky, diatomaceous mudstone from which late late Miocene diatoms assigned to Barron's (1976) Subzone A of North Pacific Diatom Zone X have been collected about 4 meters above the base (USGS loc. Mf5020) (table 2, fig. 3).

Approximately 2 to 3 meters stratigraphically higher at USGS loc. Mf5021 (fig. 3) a diatom assemblage indicative of Barron's (1976) Subzone B of North Pacific Diatom Zone X is recorded (table 2). A correlative assemblage is also

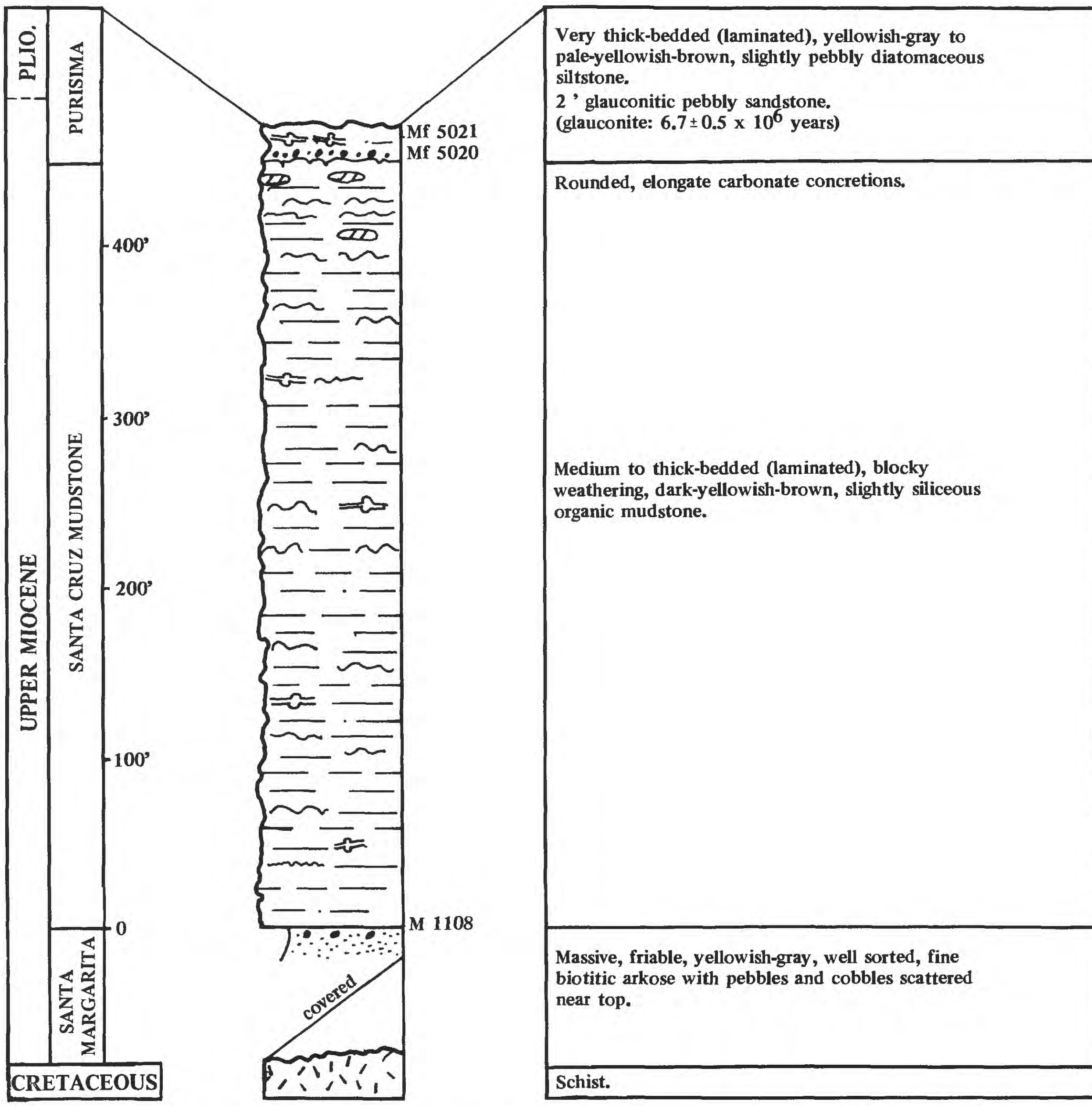


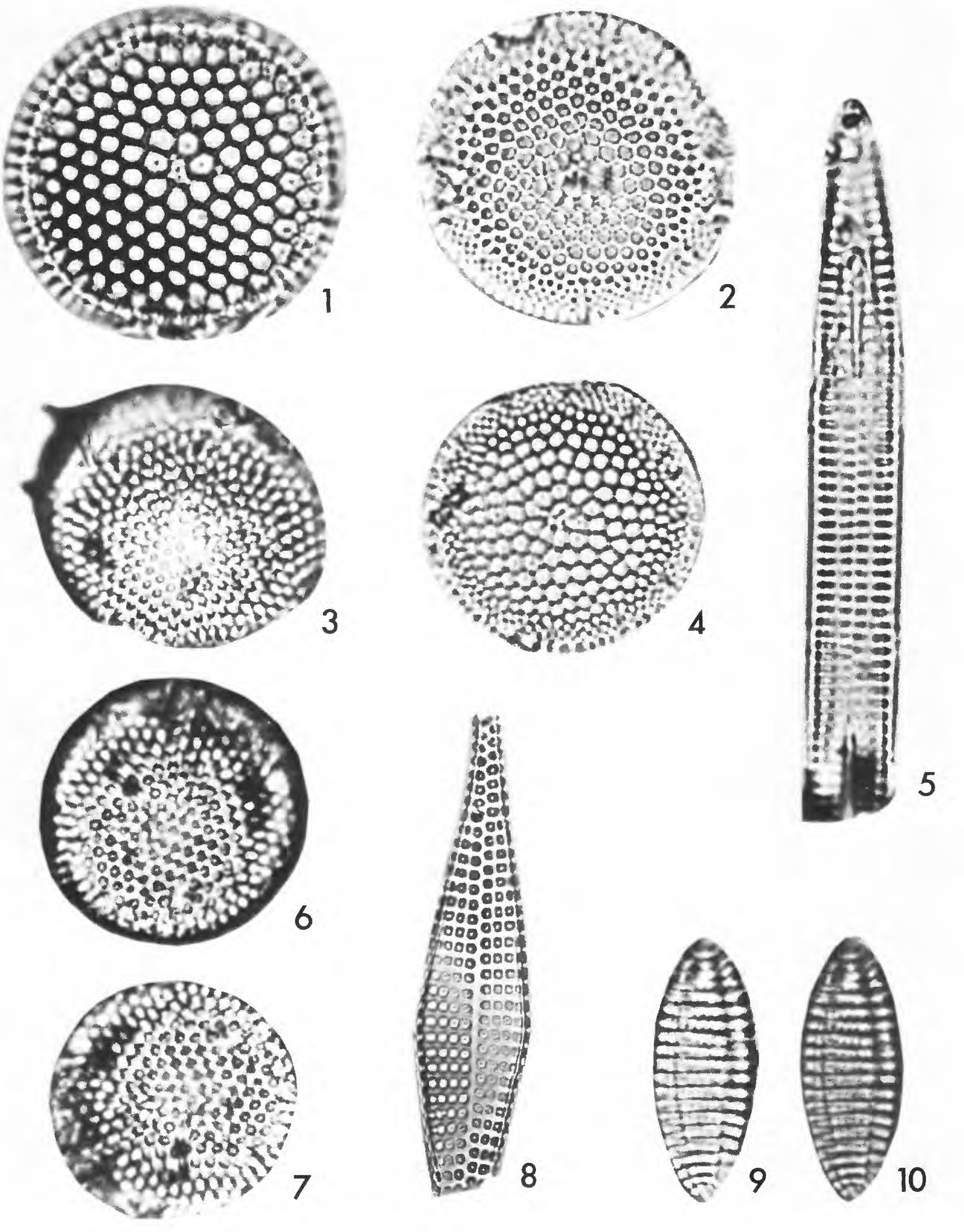
Figure 6. Stratigraphic section of the Santa Cruz Mudstone along Moore Creek and West Cliff Drive, southwestern Santa Cruz (modified from Clark, 1966).

Table 2. Selected diatoms from the Santa Cruz Mudstone of Clark (1966).

	Santa Cruz			Pt. Ano Nuevo
	Mf5020	Mf5021	Mf3676	Mf3856
Coscinodiscus temperei	R	-	-	R
Denticula kamtschatica	-	-	-	R
D. hustedtii	R	R	R	-
Nitzschia fossilis	-	R	-	R
N. sp. (cf. N. miocenica)	-	R	R	-
Rhaphoneis amphiceros var. elongata	R	-	-	-
Rouxia californica	R	-	-	-
Thalassiosira antiqua	C	C	C	C
T. convexa	-	R	R	-
T. convexa var. aspinosa	-	R	R	-
T. nativa (of Barron, 1976)	R	C	C	R
T. oestrupii	-	-	-	R
North Pacific Diatom Zone (Barron, 1976)	Xa	Xb		IX
Epoch	late Miocene			early Pliocene

present in tuffaceous siltstone beds of the Purisima Formation, about 6 to 9 meters above the contact with the Santa Cruz Mudstone (USGS loc. Mf3676) in central Santa Cruz (fig. 3, table 2). Harper (1977) places the Miocene-Pliocene boundary within this subzone in California. The occurrence of Thalassiosira convexa var. aspinosa Schrader indicates that Mf5021 and Mf3676 correlate with the Thalassiosira convexa Zone of Burckle (1972) or above and thus with or above the upper part of Paleomagnetic Epoch 6 (late late Miocene). A species of Nitzschia that closely resembles N. miocenica Burckle (pl. 1) but has a finer structure is also recorded from Mf5021 and Mf3676. Preliminary studies by Barron at DSDP Hole 438A off northwest Japan suggest that this species has a restricted occurrence within the range of N. miocenica, thus supporting its affinities with N. miocenica. Available evidence from California also point to this restricted occurrence. Using the criteria of Burckle and Opdyke (1977) samples Mf5021 and Mf3676 are thus placed in the latest Miocene.

At Point Ano Nuevo, about 30 km to the northwest, a diatom assemblage correlative with early Pliocene North Pacific Diatom Zone IX of Barron (1976) is recorded from USGS loc. Mf3856 in the Purisima Formation (table 2), approximately 15 meters above the basal sandstone and conglomerate (see Brabb and others, 1977). This suggests that the basal Purisima is slightly younger at Point Ano Nuevo than in the Santa Cruz area.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Scattered localities collected by Barron from the diatomaceous lower Purisima Formation in the Santa Cruz Mountains and in the Santa Cruz area all contain diatom assemblages similar to those recorded in table 2, that is, assemblages correlative with the interval from late late Miocene Subzone A of North Pacific Diatom Zone X through early Pliocene North Pacific Diatom Zone IX of Barron (1976).

Mollusks have not been recorded from the seacliff exposures at Santa Cruz but the basal 60 m of the Purisima in the southeastern part of the Felton quadrangle, to the north, has yielded common species of _Lucinoma_ cf. _L. annulata_ (Reeve) and a few other species (Clark, 1966) suggestive of middle to outer sublittoral depths. Glauconite from the basal fine- to very fine grained sandstone at the base of the Purisima Formation has been dated at 6.7±0.5 my by J. D. Obradovich (_in_ Clark, 1966) suggesting a latest Miocene age for the lowermost part of the formation which agrees well with the diatom evidence.

The Santa Cruz Mudstone is exposed in the seacliffs westward to Natural Bridges Beach State Park, the final stop of this segment of the trip. The mudstone is siliceous and locally contains thin interbeds of porcelanite in some coastal exposures (Clark, 1966). Light-gray dolomitic concretions that range from 1 to 2 m in thickness occur commonly in seacliff exposures in this area. The mudstone contains abundant indeterminate diatoms and sponge spicules. A benthic foraminiferal assemblage about 15 m below the top of the Santa Cruz Mudstone identified by Clark (1966) includes: _Bolivina_ cf. _B. seminuda_ Cushman, _Bolivina_ aff. _B. vaughani_ Natland, _Buliminella dubia_ Barbat and Johnson, and _Buliminella elegantissima_ (d'Orbigny). Clark (1966) reports scattered marine macrofossils mostly from inland exposures near Scotts Valley, about 10 km north of Santa Cruz. Included are the ophiuroid _Amphiura sanctaecrucis_ Arnold, the bivalves _Lucinoma_ cf. _L. annulata_ (Reeve) and _Yoldia_ sp., and the late Miocene spatangoid echinoid _Megapetalus_ sp.

Plate 1

Selected marine diatoms from the Purisima Formation in the Santa Cruz area.

1. _Thalassiosira antiqua_ (Grunow) Cleve-Euler. Diameter 24 um. Sample USGS loc. Mf3676.

2, 4. _Thalassiosira nativa_ Sheshukova-Poretzkaya (of Barron, 1976). 2, diameter 23 um; 4, diameter 20.5 um. Sample USGS loc. Mf3676.

3. _Thalassiosira convexa_ Muchina. Diameter, 21.5 um. Sample USGS loc. Mf3676.

5. _Rouxia californica_ Peragallo (fragment). Width (transapical axis), 6 um. Sample USGS loc. Mf5020.

6, 7. _Thalassiosira convexa_ var. _aspinosa_ Schrader. 6, diameter, 19.3 um; 7, diameter 19 um. Sample USGS loc. Mf3676.

8. _Rhaphoneis amphiceros_ var. _elongata_ Peragallo (fragment). Width (transapical axis), 16 um. Sample USGS loc. Mf5020.

9, 10. _Nitzschia_ sp. (cf. _N. miocenica_ Burckle). 9, length (apical axis), 22.2 um; 10, length 18.2 um. Sample USGS loc. Mf3676. This species closely resembles _N. miocenica_ Burckle, but contains more closely spaced costae (10-11 in 10 um).

Figure 7. Santa Cruz Mudstone at Natural Bridges State Beach west of Santa Cruz.

SANTA CRUZ MUDSTONE AT NATURAL BRIDGES BEACH STATE PARK (STOP 4)

The Natural Bridges west of Santa Cruz are eroded into a massive outcrop of Santa Cruz Mudstone that strikes west-southwestward offshore (fig. 7). Excellent exposures of this organic mudstone occur in the low seacliff on the west side of Moore Creek. The type section of the formation extends from the conformable contact with underlying Santa Margarita Formation on Moore Creek southward 1 1/2 km to the coast and thence eastward about 1 km to the seacliff exposure of the contact with the Purisima Formation (Clark, 1966).

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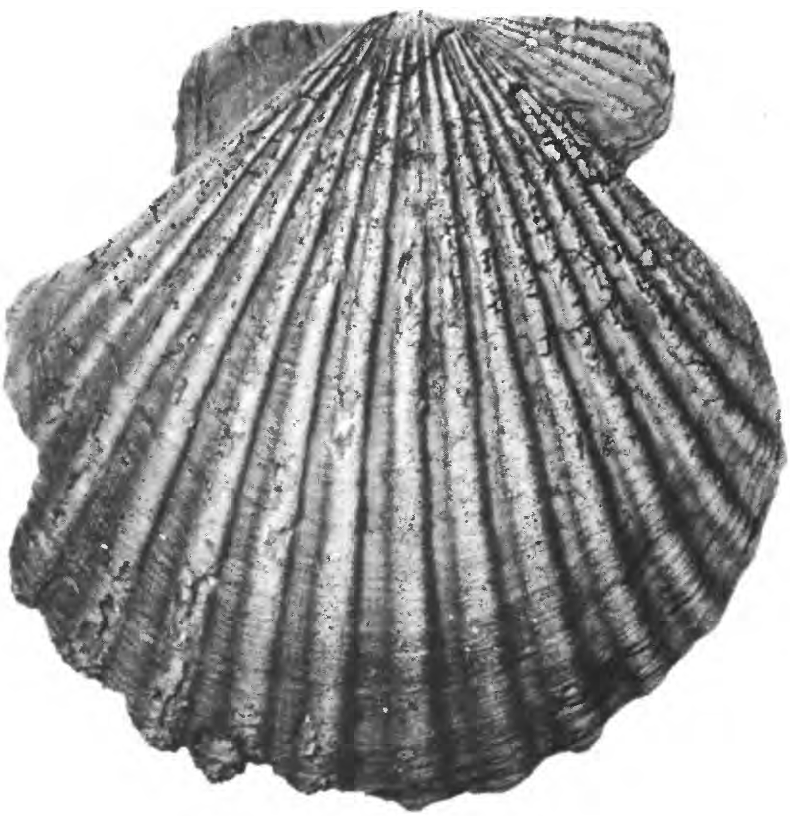

Lryopecten crassicardo (Conrad), a middle and late Miocene scallop (USNM 254389, USGS loc. M2023, Santa Margarita Formation)

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